

Truth and Beauty Together: Evidence for s-channel Single Top Production



UNIVERSITY *of*
ROCHESTER

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on behalf of DØ Collaboration
Wine & Cheese Seminar
June 21st, 2013

The Top (Truth) Quark

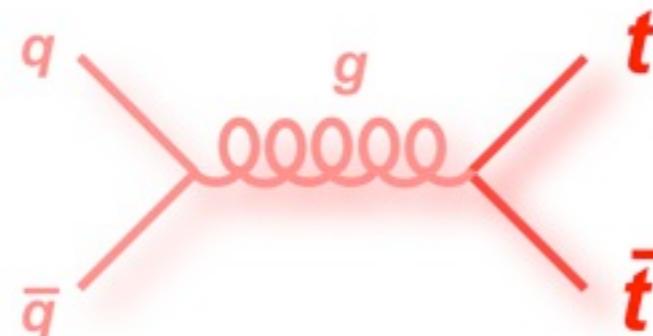
- Discovered by CDF and DØ at the Tevatron in 1995
- Heaviest known particle: 173.2 ± 0.9 GeV ([arXiv:1305.3929](#))
 - couples very strongly to the Higgs because of its mass
 - Sensitive to new physics
 - Decays as a free quark: short lifetime
 - width was measured in single top analysis
[PRD 85 091194 \(2012\)](#)

Three generations of matter (fermions)				
	I	II	III	
mass	$2.4 \text{ MeV}/c^2$	$1.27 \text{ GeV}/c^2$	$171.2 \text{ GeV}/c^2$	0
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	u	c	t	γ
	up	charm	top	photon
Quarks				
mass	$4.8 \text{ MeV}/c^2$	$104 \text{ MeV}/c^2$	$4.2 \text{ GeV}/c^2$	0
charge	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	d	s	b	g
	down	strange	bottom	gluon
Leptons				
mass	$<2.2 \text{ eV}/c^2$	$<0.17 \text{ MeV}/c^2$	$<15.5 \text{ MeV}/c^2$	$91.2 \text{ GeV}/c^2$
charge	0	0	0	1
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
name	v _e	v _μ	v _τ	Z ⁰
	electron neutrino	muon neutrino	tau neutrino	Z boson
Gauge bosons				
mass	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$80.4 \text{ GeV}/c^2$
charge	-1	-1	-1	± 1
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name	e	μ	τ	W [±]
	electron	muon	tau	W boson
<small>© 2013 Fermilab. All rights reserved.</small>				
<small>Periodic table of particles</small>				

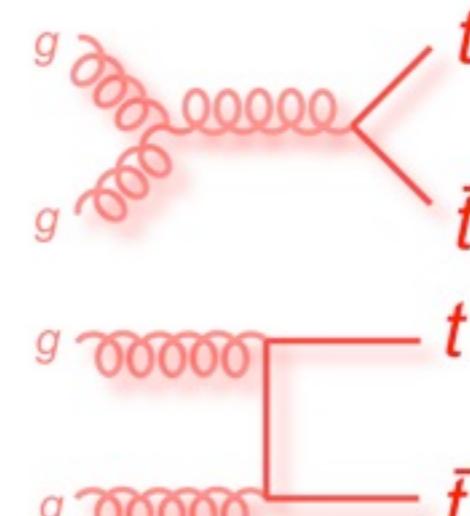
- Measurements:
 - production cross section
 - mass
 - angular properties of the decay products
 - width and lifetime
 - charge, $m(t)-m(\bar{t})$

Top Production at Hadron Colliders

- Strong interaction: top pair

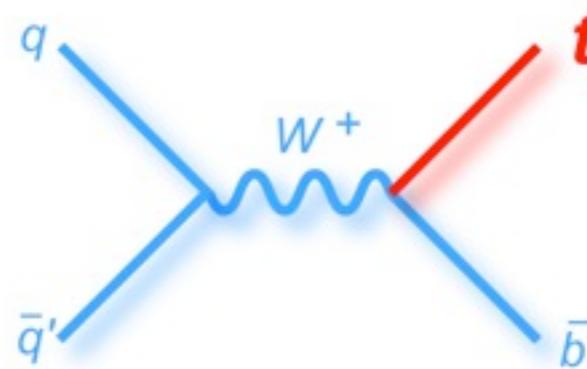


$q\bar{q}$ annihilation

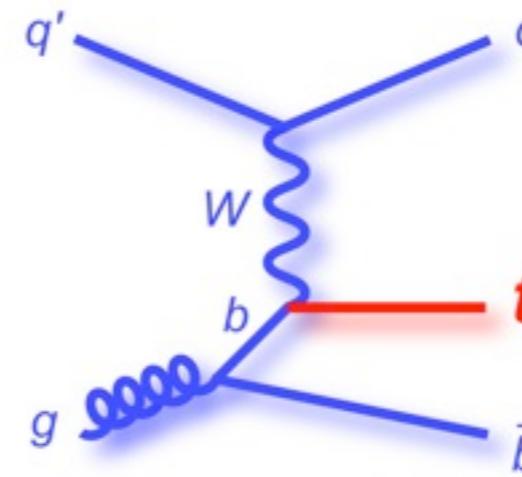


gg fusion

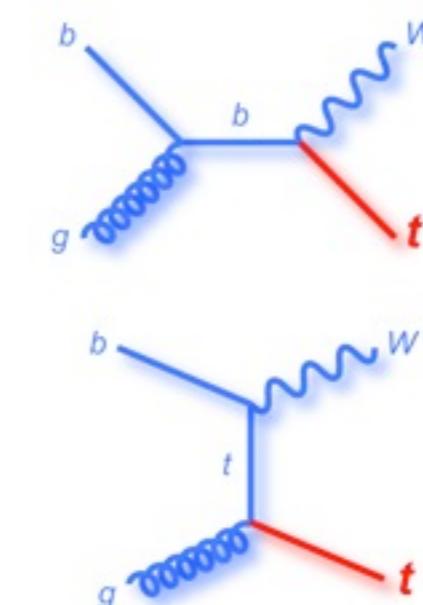
- Electroweak interaction: single top



s-channel (tb)



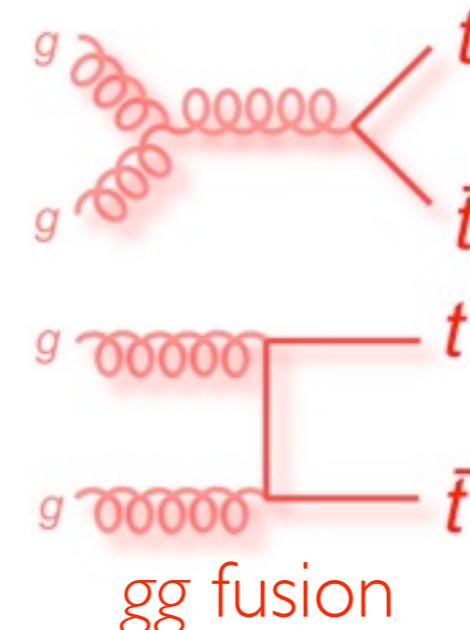
t-channel (tqb)



Associated (tW)

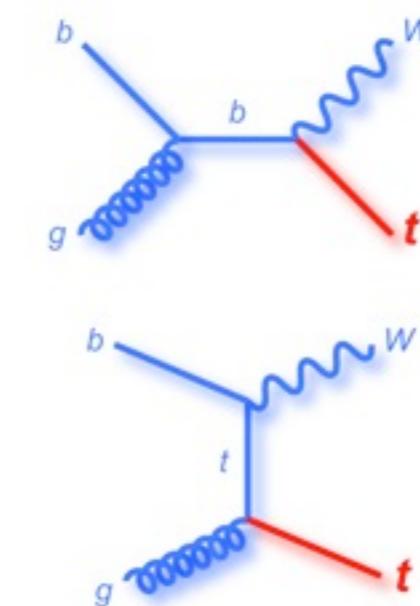
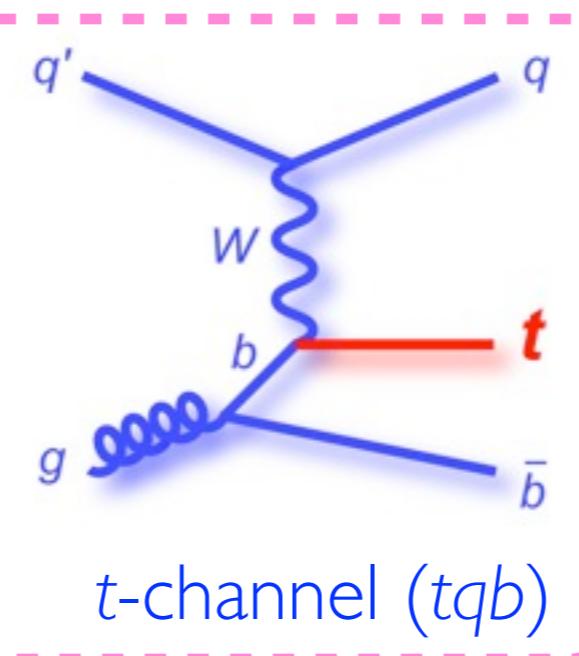
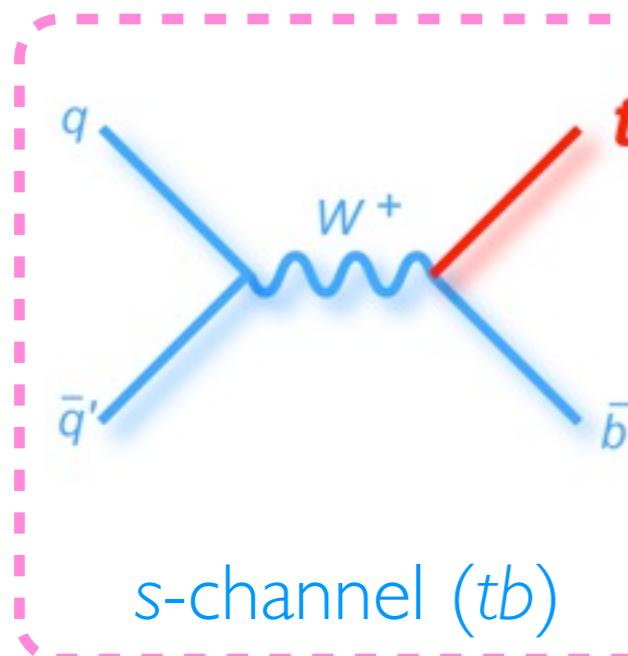
Top Production at Hadron Colliders

- Strong interaction: top pair



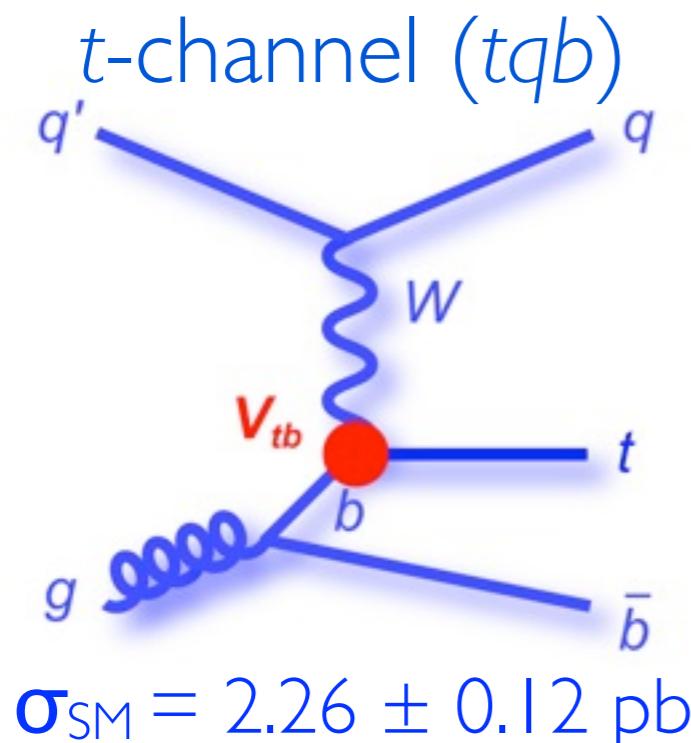
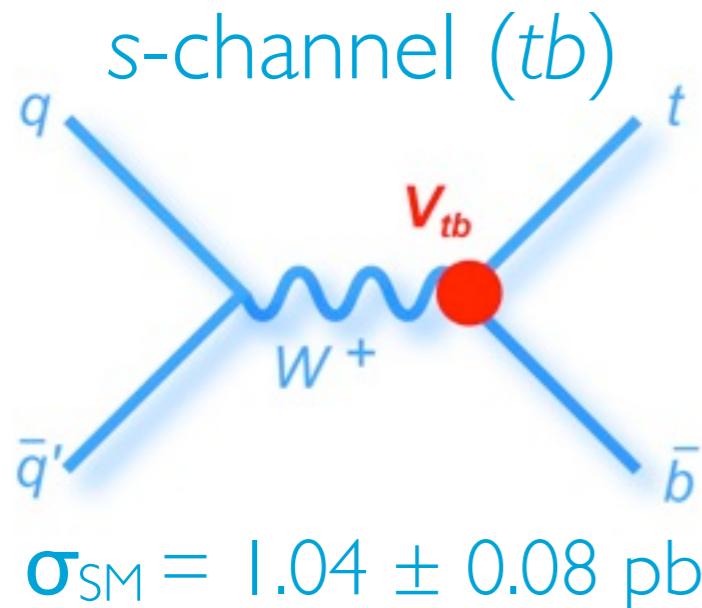
Main modes
at Tevatron

- Electroweak interaction: single top



Associated (tW)

EW Top Quark Production

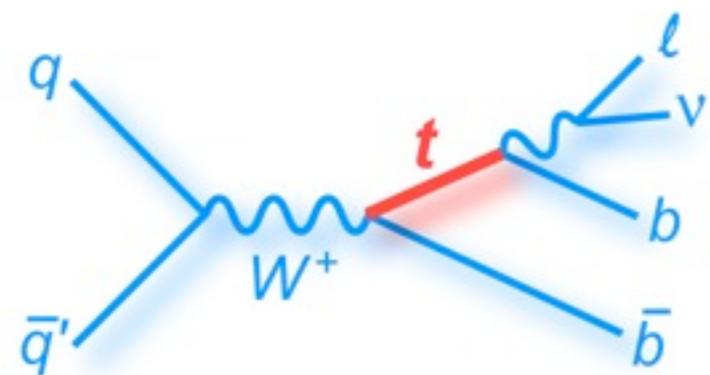
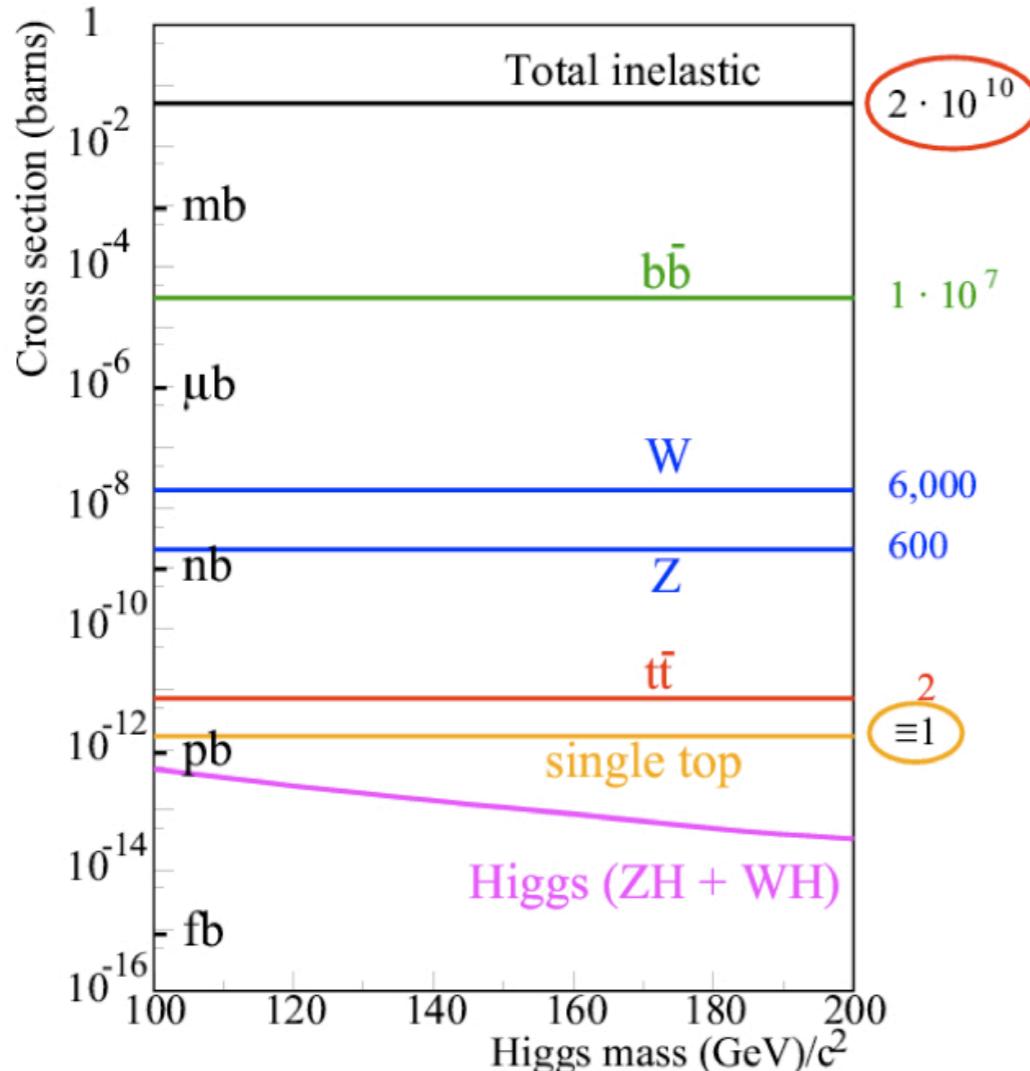


$$M_{\text{top}} = 172.5 \text{ GeV}$$

N. Kidonakis, PRD 74.114012 (2006)

- Measure the two important single top-quark production modes at Tevatron: s and t channel
- Directly probe the CKM matrix element $|V_{tb}|$
- Measure the top decay width
- New physics can change σ_{tb} and σ_{tqb} differently:
 - σ_{tb} : New bosons
 - σ_{tqb} : FCNC, anomalous couplings
- σ_{tw} at the Tevatron is negligible

A Challenging Analysis



- Small cross section: ~ 3 pb
 - Tevatron produced 32k single top events
 - Analyze leptonic final state: 6.8k single top events
- Background dominated
 - Main background: $W+jets$
- To observe $t\bar{b} + t\bar{q}b$, needed 50 times more data than the top pair observation! (CDF, DØ)
 - PRL 103 092001 (2009)

LHC: Limited $t\bar{b}$ Production

σ (pb) ~NNLO	$t\bar{b}$	$t\bar{q}b$	tW
Tevatron (1.96 TeV)	1.04	2.26	0.3
	x4	x30	x50
LHC (7 TeV)	4.6	64.6	15.7

Status up to Today

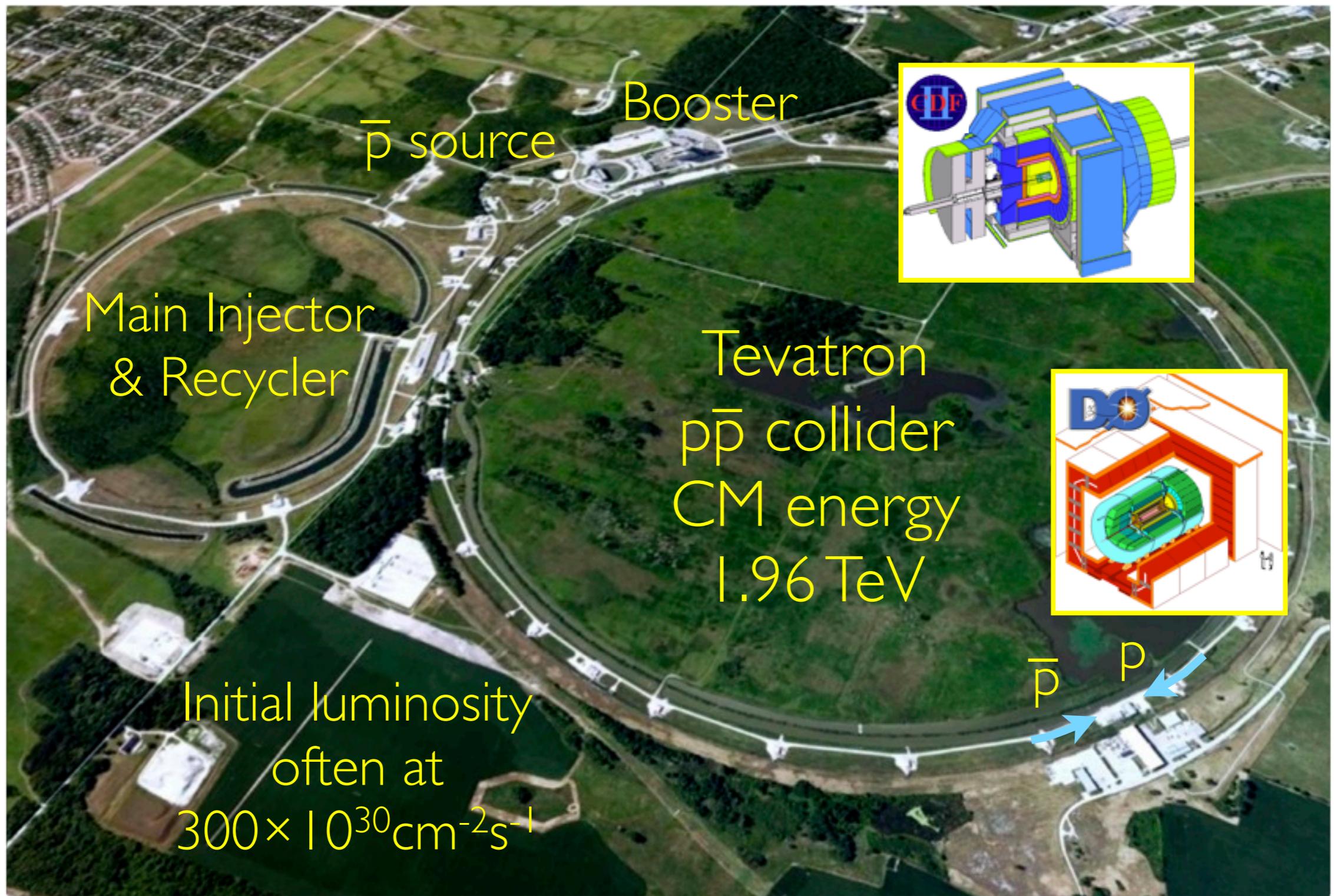
σ (pb) ~NNLO	$t\bar{b}$	$t\bar{q}b$	tW
Tevatron Prediction (1.96 TeV)	1.04	2.26	0.3
CDF (7.5 fb ⁻¹)	1.8±0.6	1.49±0.45	-
DØ (5.4 fb ⁻¹)	0.98±0.63	<input checked="" type="checkbox"/> 2.9±0.59	-
LHC Prediction (7 TeV)	4.6	64.6	15.7
ATLAS (0.7-2.1 fb ⁻¹)	< 20.5 (95% C.L.)	<input checked="" type="checkbox"/> 83±20	<input type="checkbox"/> 17±6
CMS (1.2-4.9 fb ⁻¹)	-	<input checked="" type="checkbox"/> 67±6	<input type="checkbox"/> 16±5

Evidence (3 SD)

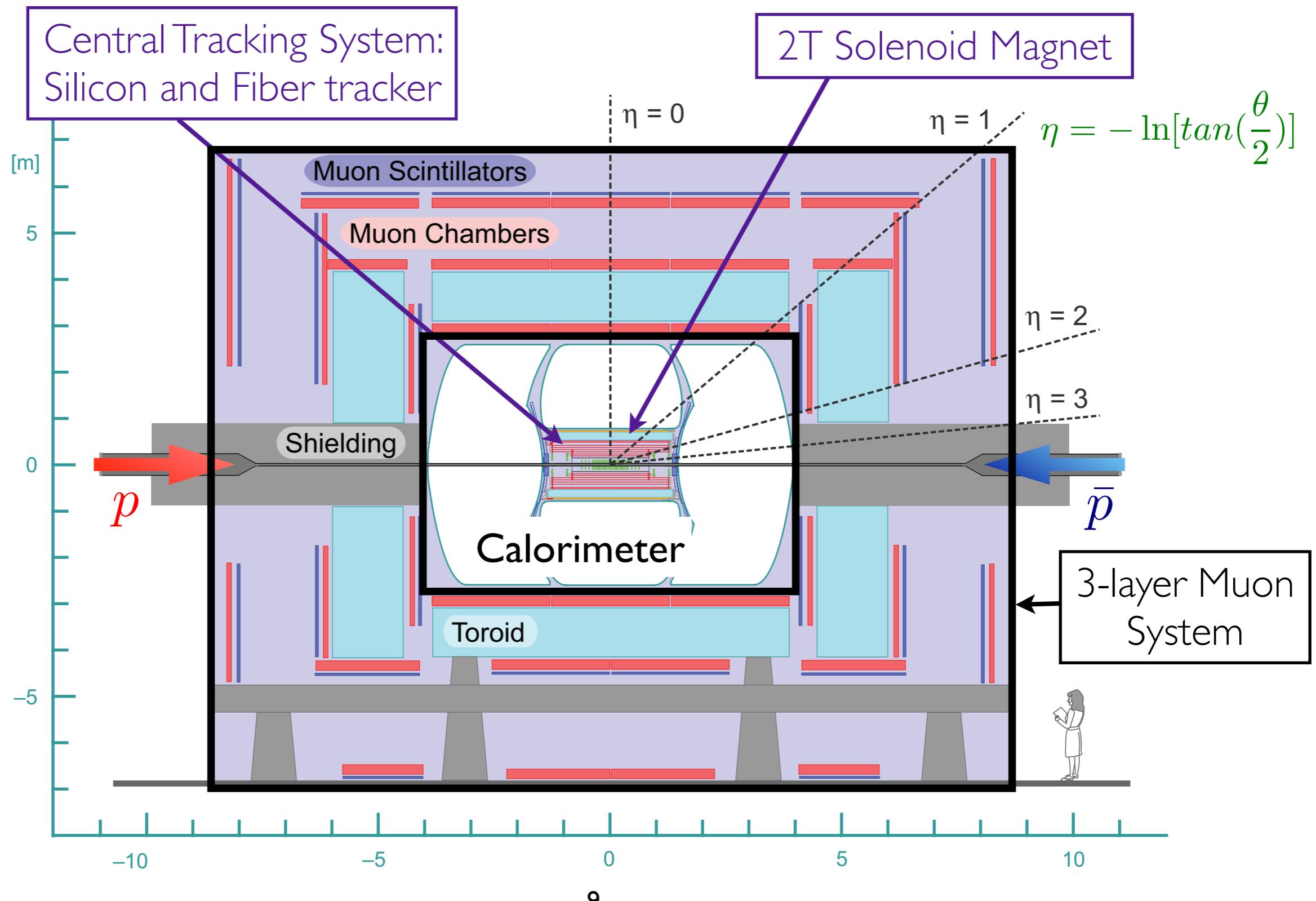
7

Observation (5 SD)

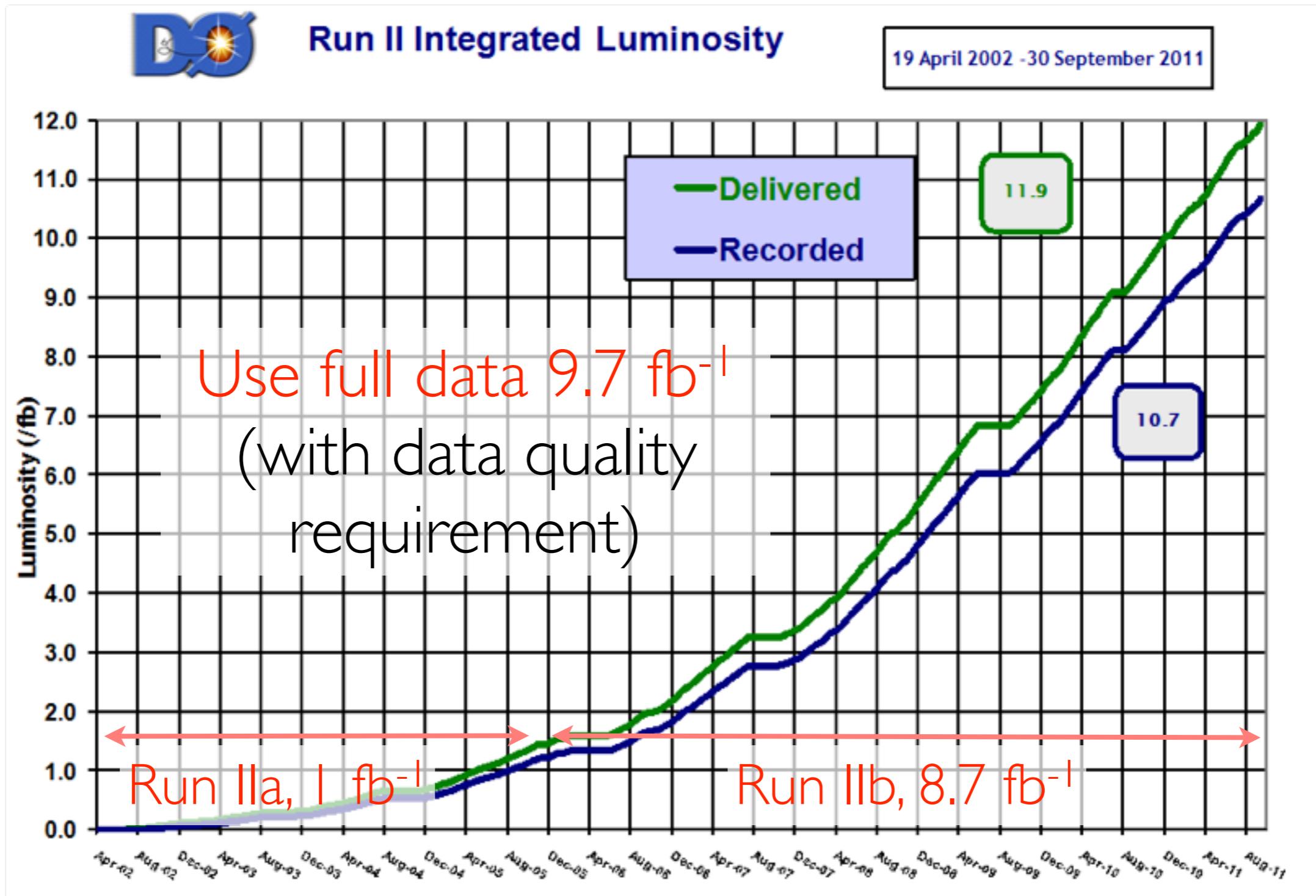
Fermilab Tevatron



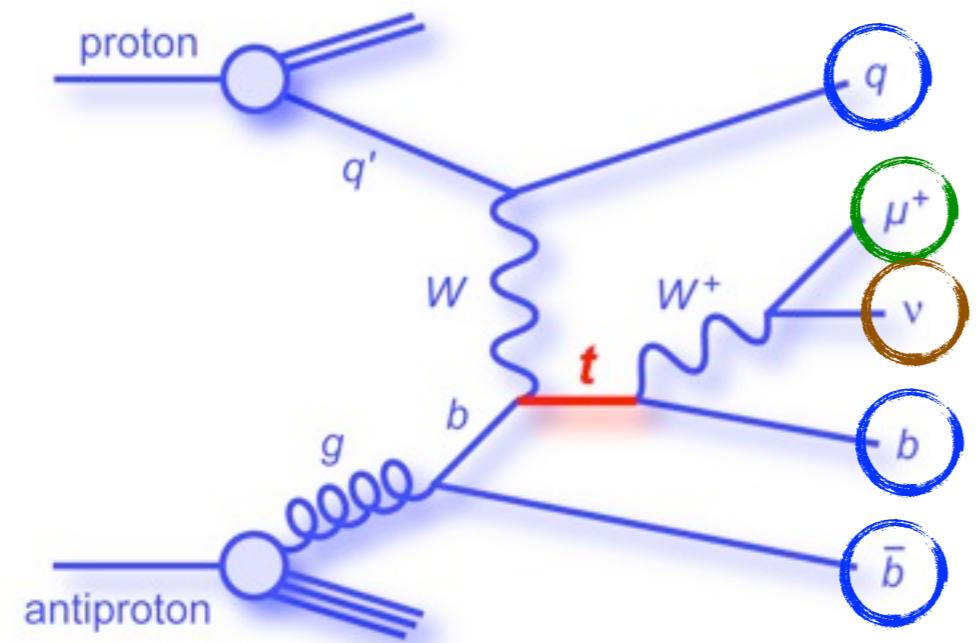
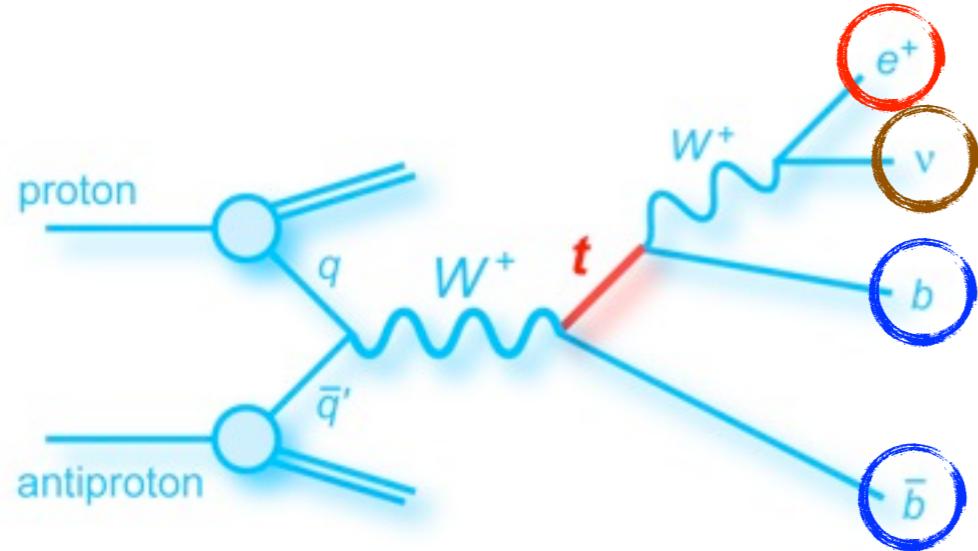
DØ Detector



Data Taking

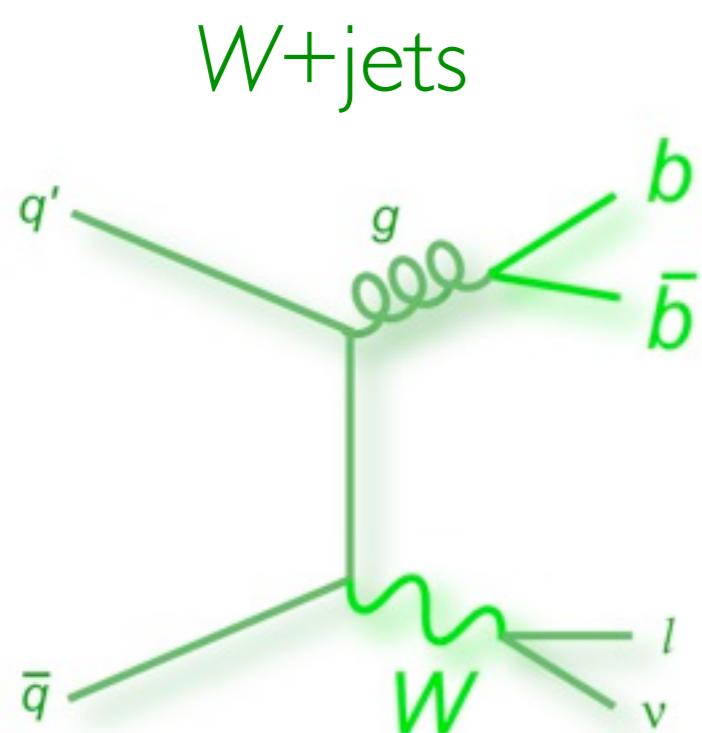
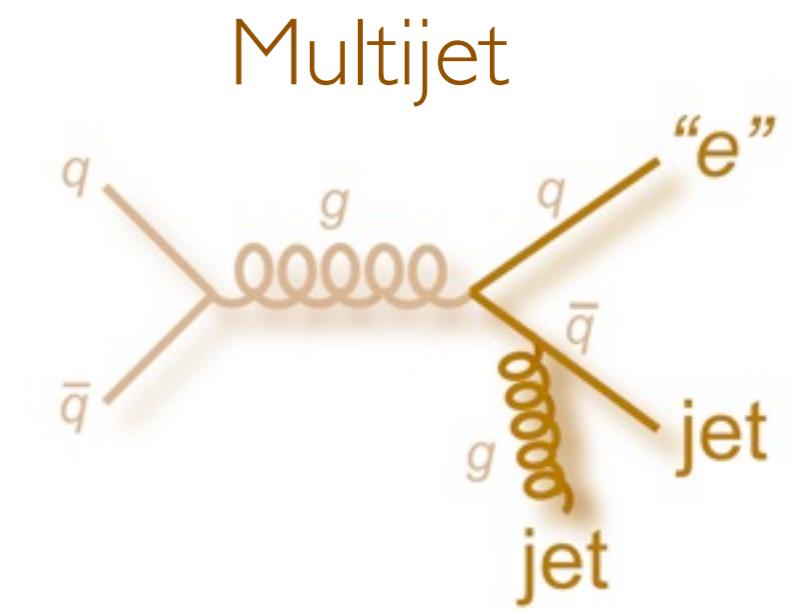
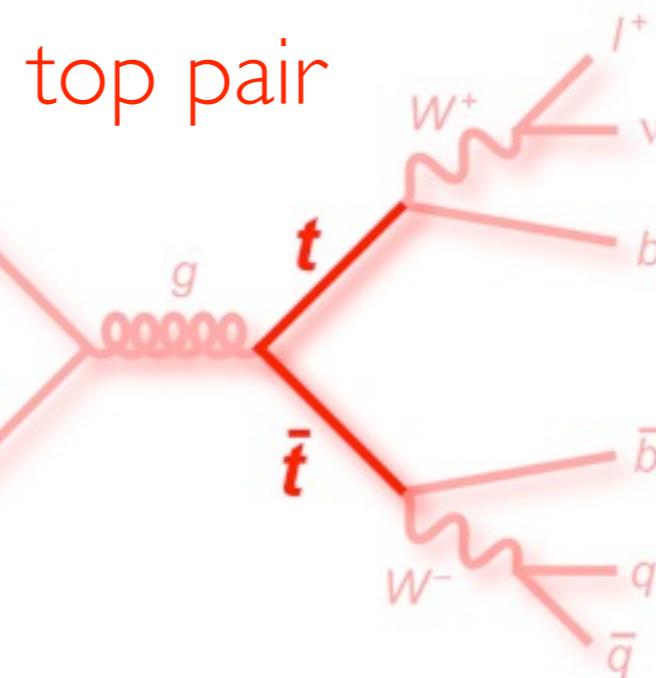
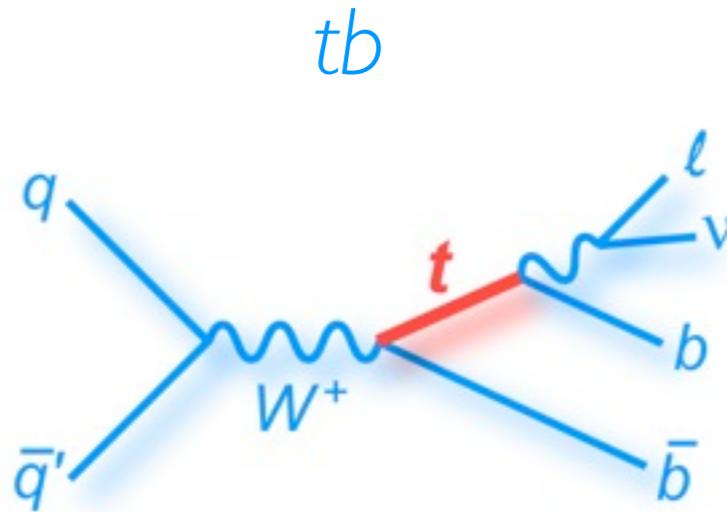


Event Selection



- Only one high p_T isolated electron or muon: $p_T > 20 \text{ GeV}$
 - electron: $|n| < 1.1$
 - muon: $|n| < 2.0$
- Two or three jets
 - $p_T > 20 \text{ GeV}, |n| < 2.5$
 - The leading jet $p_T > 25 \text{ GeV}$
- Missing transverse energy $> 20 \text{ GeV}$
- $H_T > 120 \text{ GeV}$
 - $H_T = \text{all jet } p_T + \text{lepton } p_T + \text{missing transverse energy}$

Signal & Background Simulation



- Signals: CompHEP (NLO)+Pythia
- $W+jets$ & top pair: Alpgen+Pythia
 - Correct Alpgen (LL) to NLO
 - e.g. a factor 1.9 for $W+bb$
- Multijet: Data with non-isolated lepton

W +jets & Multijet Normalization

- Determine the overall scales of multijet and W +jets background simultaneously

$$N_{\text{loose}} = N_{\text{loose}}^{\text{fake-}\ell} + N_{\text{loose}}^{\text{real-}\ell}$$

$$N_{\text{tight}} = \epsilon_{\text{fake-}\ell} N_{\text{loose}}^{\text{fake-}\ell} + \epsilon_{\text{real-}\ell} N_{\text{loose}}^{\text{real-}\ell}$$

$W+jets$ & Multijet Normalization

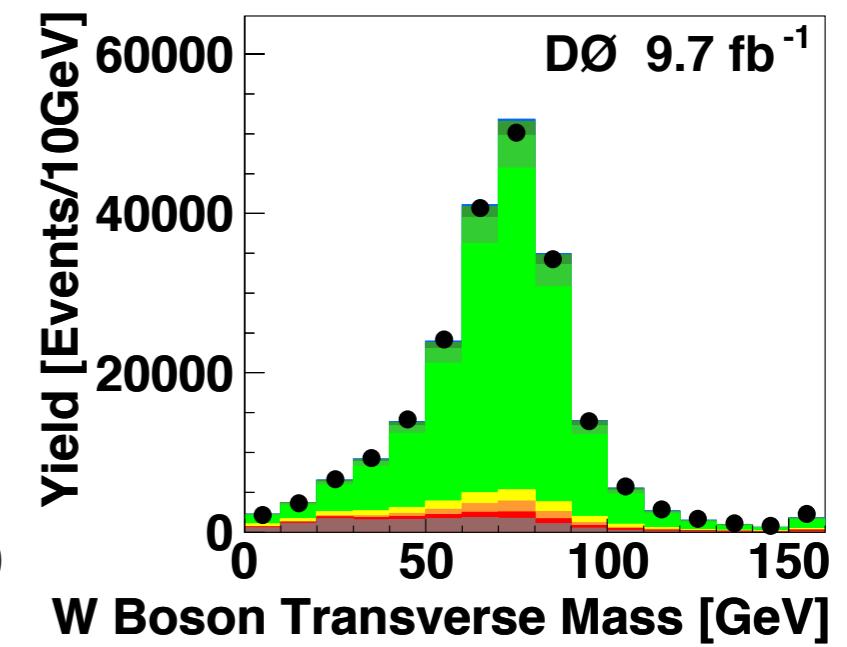
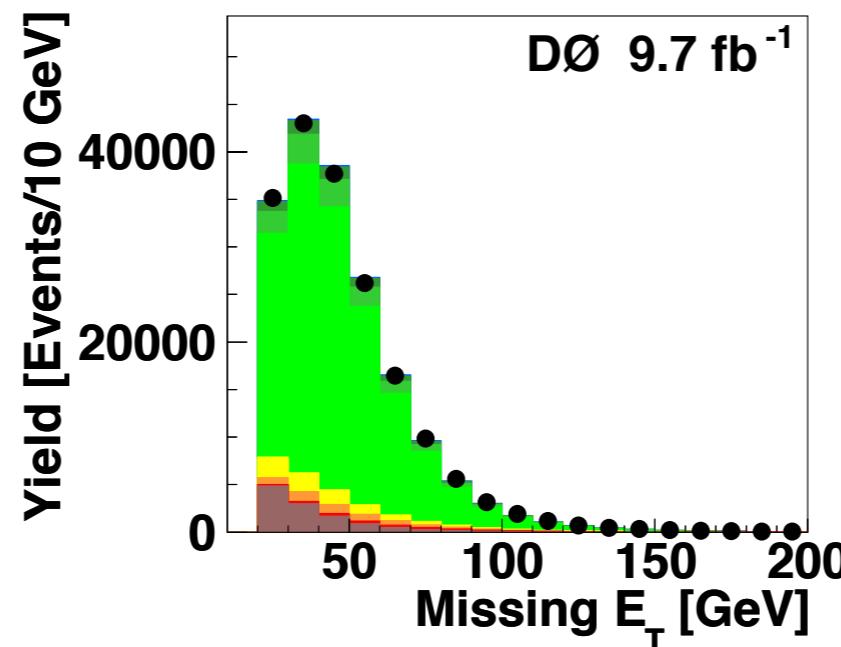
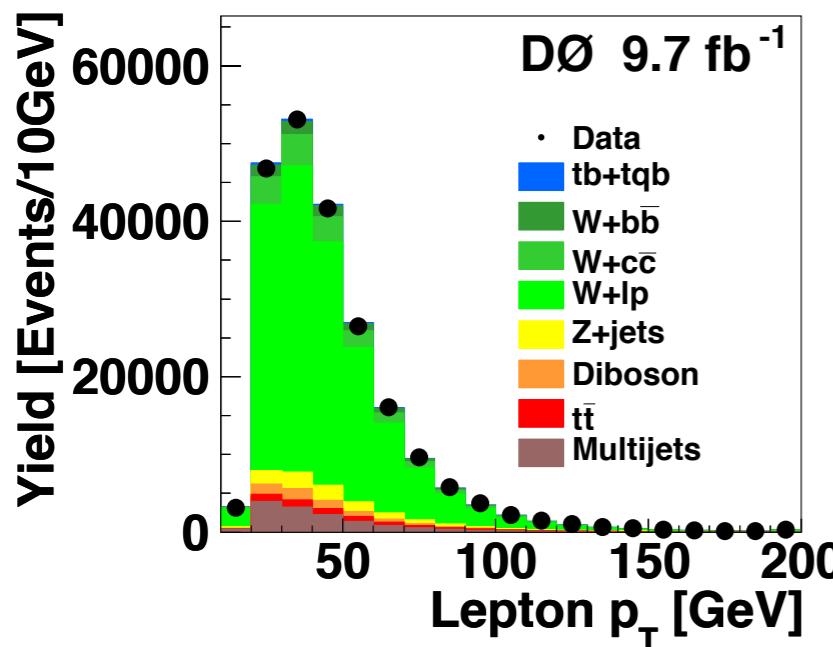
- Determine the overall scales of multijet and $W+jets$ background simultaneously

Known from the selected data samples

$$N_{\text{loose}} = N_{\text{loose}}^{\text{fake-}\ell} + N_{\text{loose}}^{\text{real-}\ell}$$

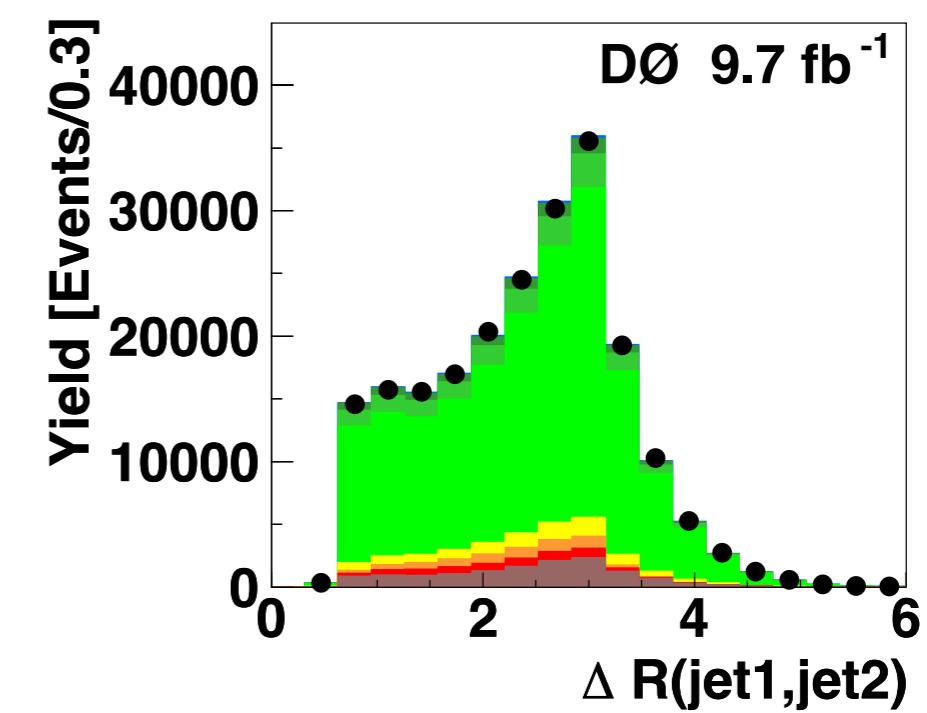
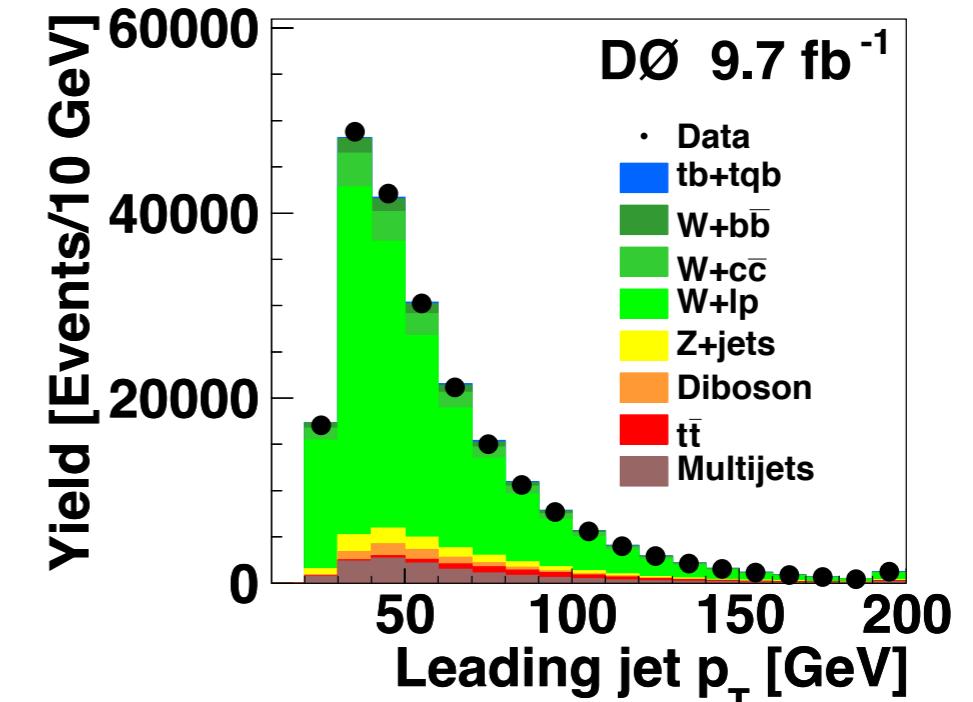
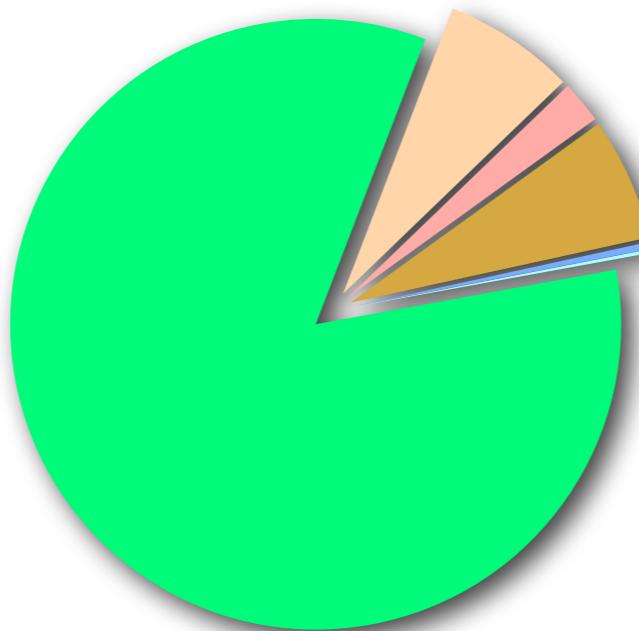
$$N_{\text{tight}} = \epsilon_{\text{fake-}\ell} N_{\text{loose}}^{\text{fake-}\ell} + \epsilon_{\text{real-}\ell} N_{\text{loose}}^{\text{real-}\ell}$$

Determined from MC and data samples

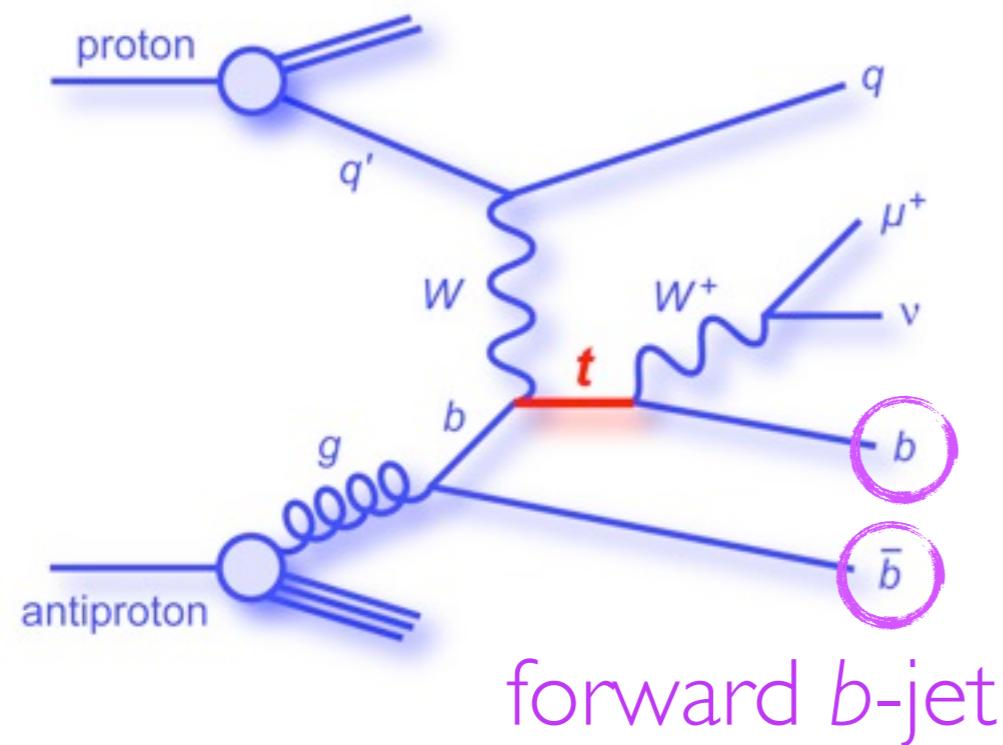
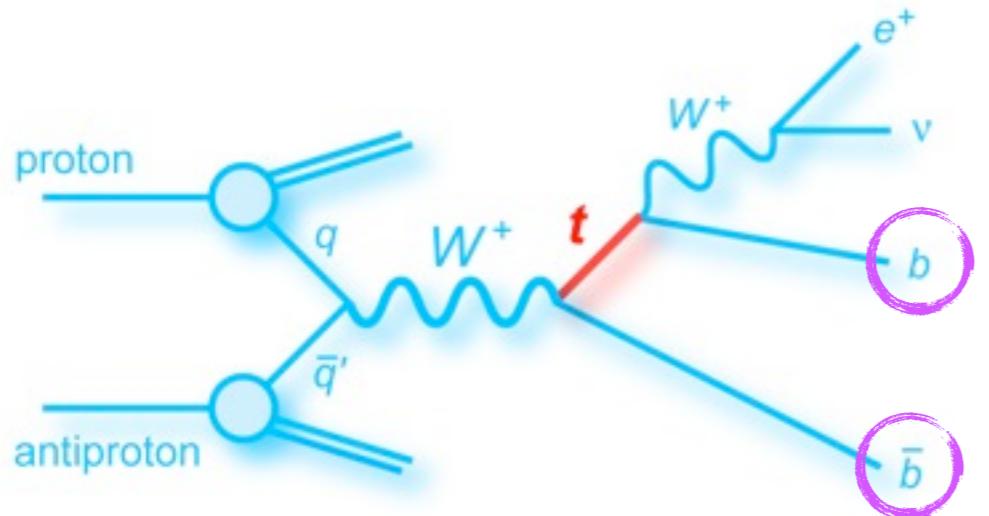


Background Modeling

- Dominated by backgrounds
- Correct the efficiency of the simulated samples to that of data
- Reweight the angular distributions of $W+jets$ MC to data

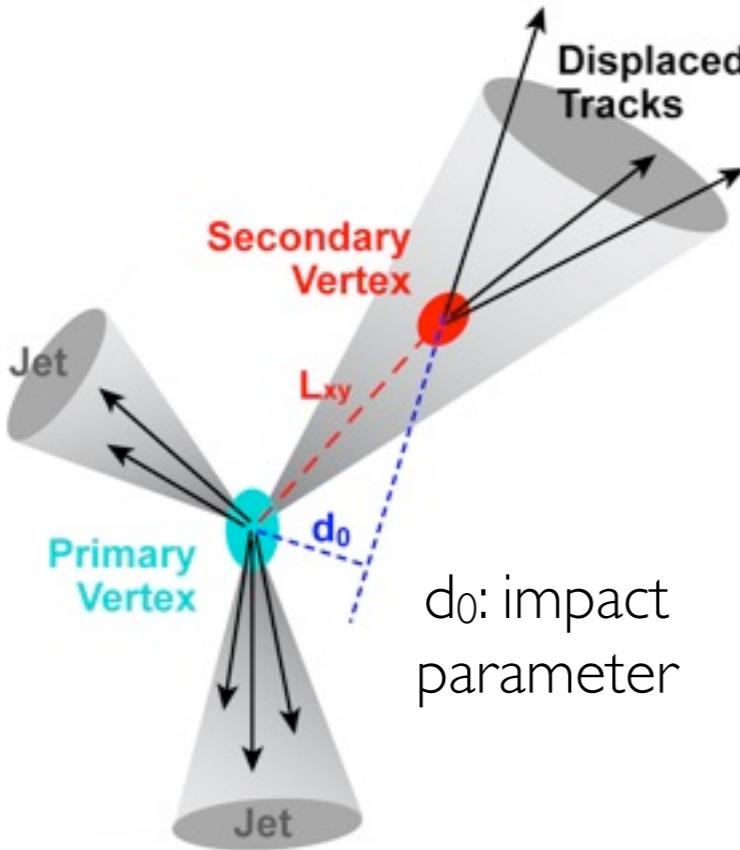


Event Selection

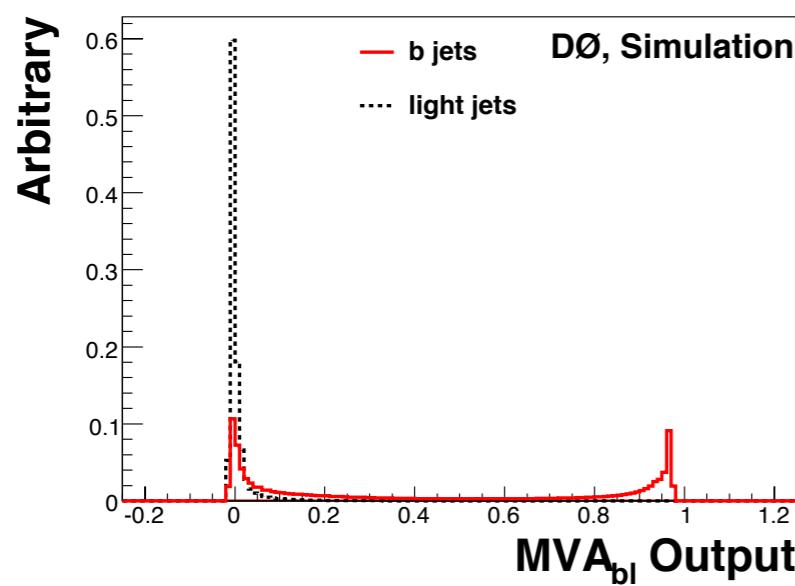


- One high p_T isolated electron or muon: $p_T > 20 \text{ GeV}/c$
 - electron: $|n| < 1.1$
 - muon: $|n| < 2.0$
- Two or three jets
 - $p_T > 20 \text{ GeV}/c, |n| < 2.5$
 - The leading jet $p_T > 25 \text{ GeV}/c$
- Missing transverse energy $> 20 \text{ GeV}/c$
- Total transverse energy (H_T)
- Require one or two identified b -jets (b -tagging)

b -Jet Identification

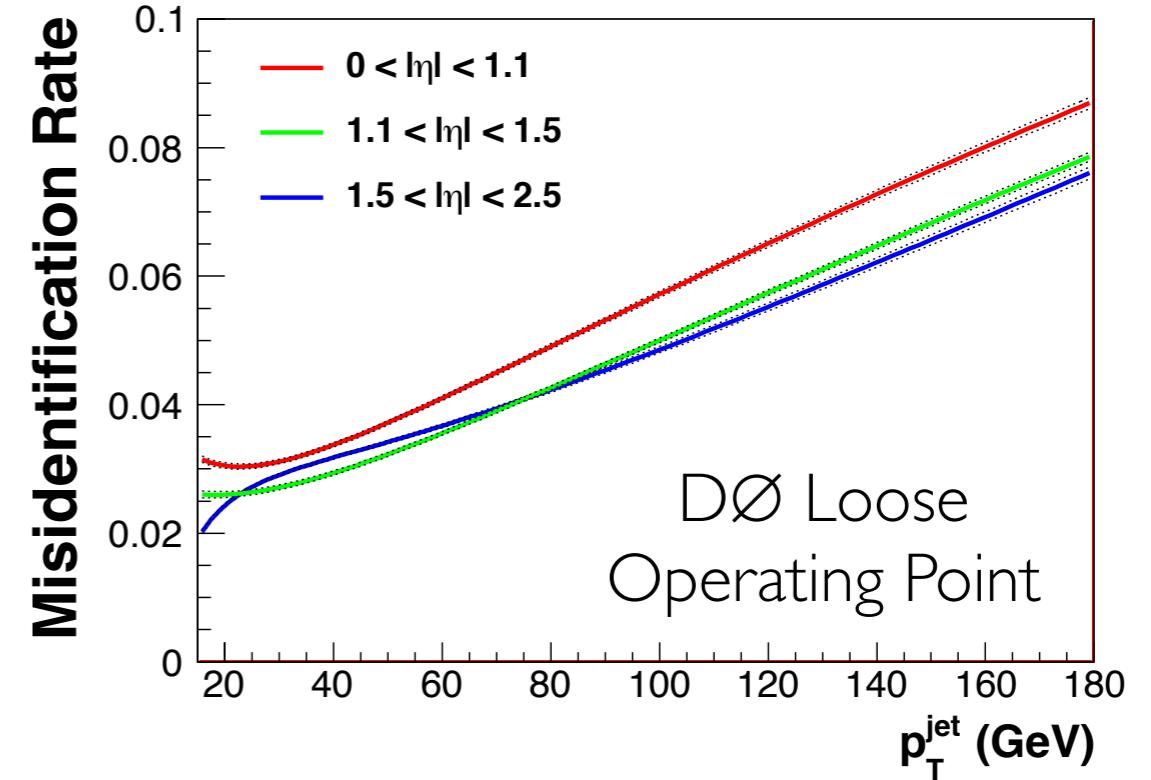
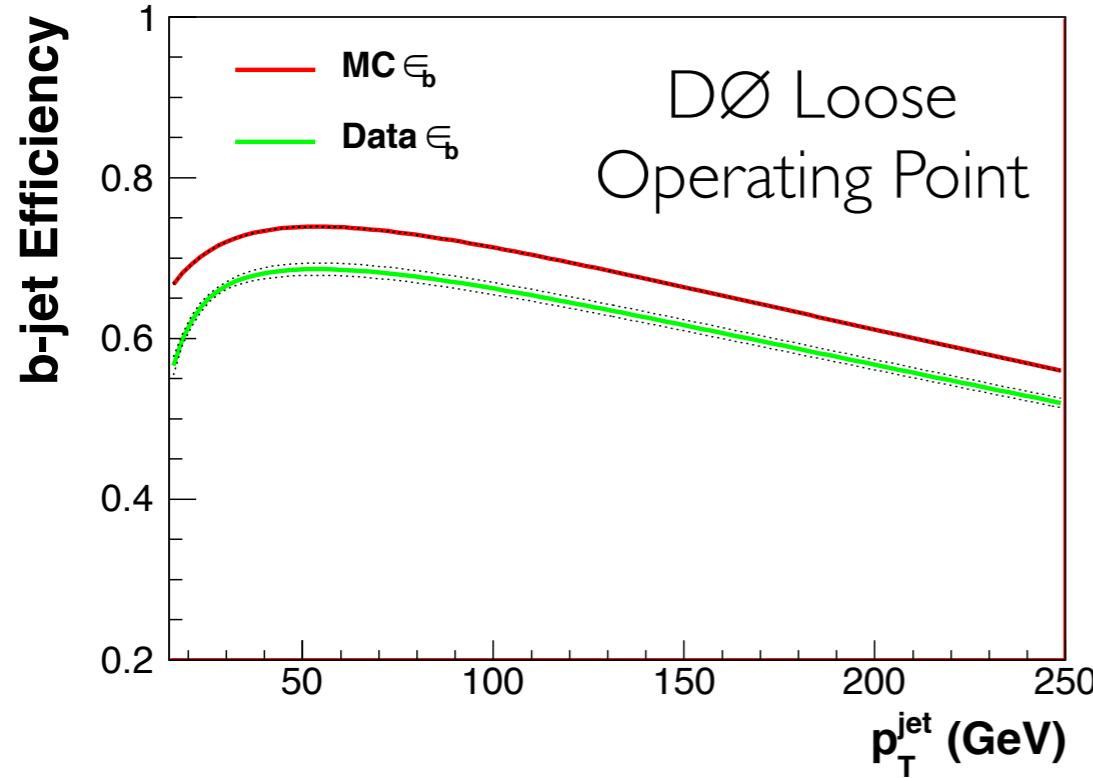


d_0 : impact parameter



- Identify b -jet from u, d, s, c , and g jets
 - reduces a lot of backgrounds
- Features of b -hadron in b -jet
 - Long lifetime (~ 1 ps, $L_{xy} \sim 3$ mm)
 - Large invariant mass
- Reconstruct a secondary vertex
- Make use of the displaced tracks (with large impact parameter)
- Use a multivariate technique to combine this information

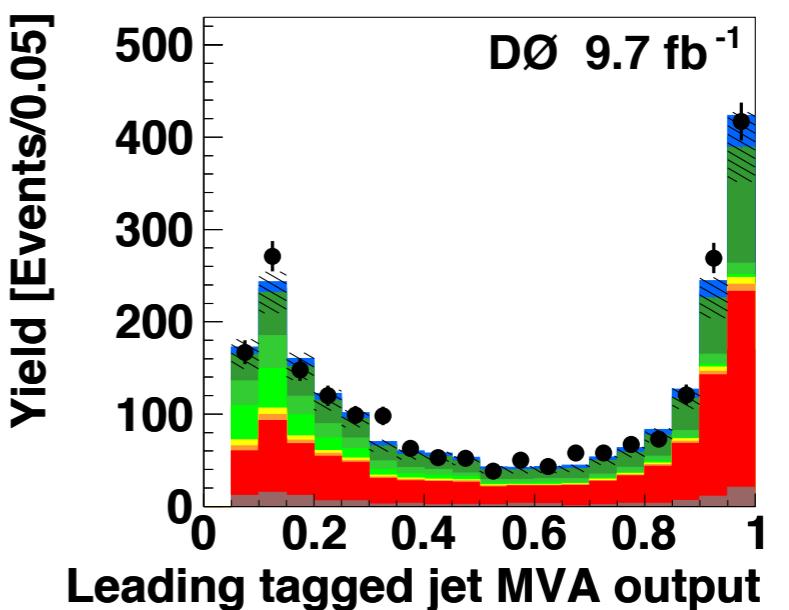
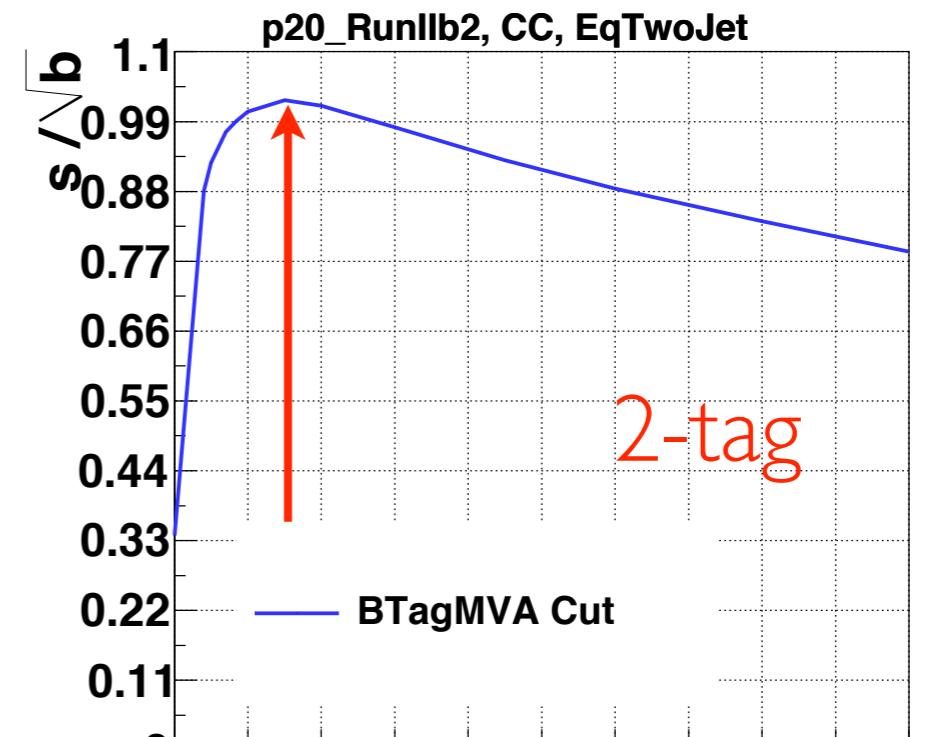
b -ID Efficiency



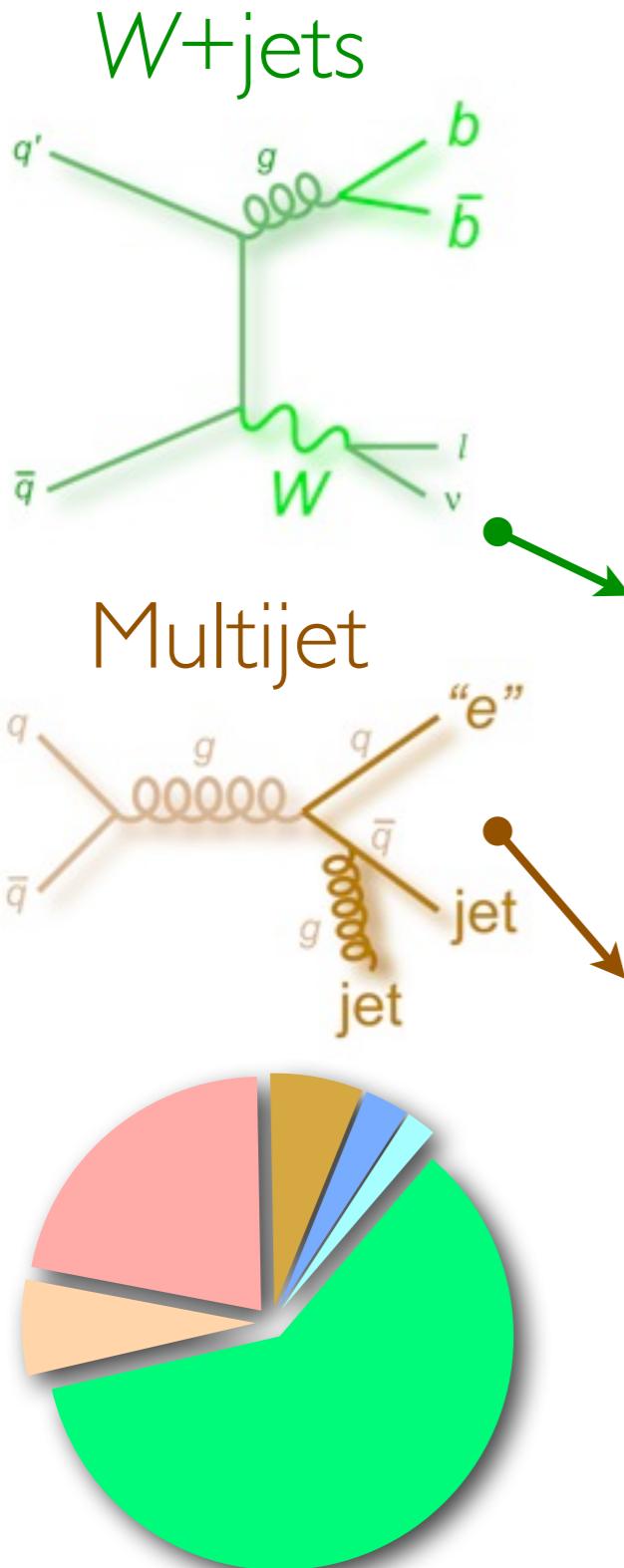
- b -identification efficiency: (50-70)%
- Misidentification rate: (3-8)%
- Obtain scale factors to correct the MC samples

b -ID Cut Optimization

- Calculate s/\sqrt{b} from the predicted signal and background events with each b -ID cut
- Maximize the $t\bar{b}$ signal rate
 - The $t\bar{b}$ events have two central b -jets
 - 2-tag channel: 2 jets with Loose b -ID
 - 1-tag channel: 1 jet with Tight b -ID, veto the 2nd jet with Loose b -ID
 - Non-overlapping categories

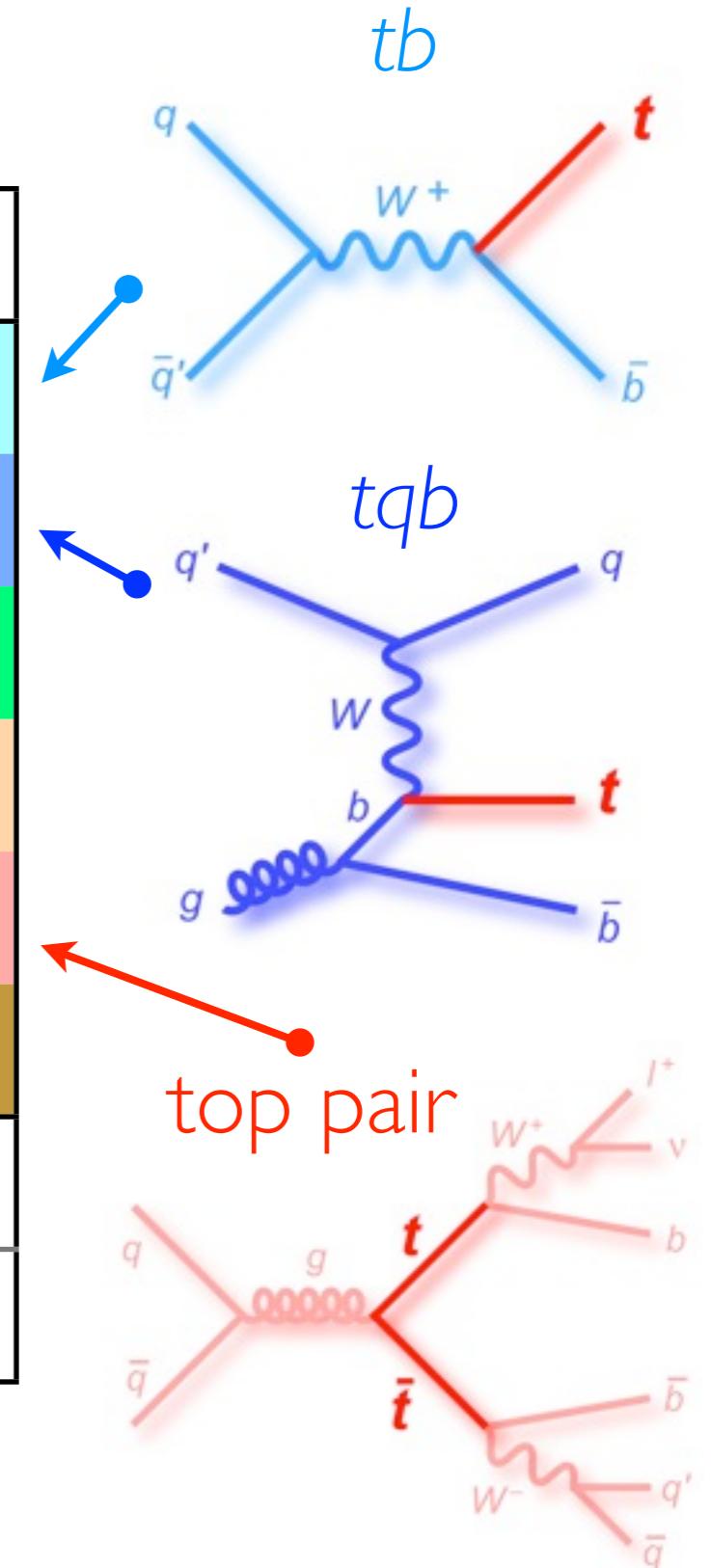


Event Yield

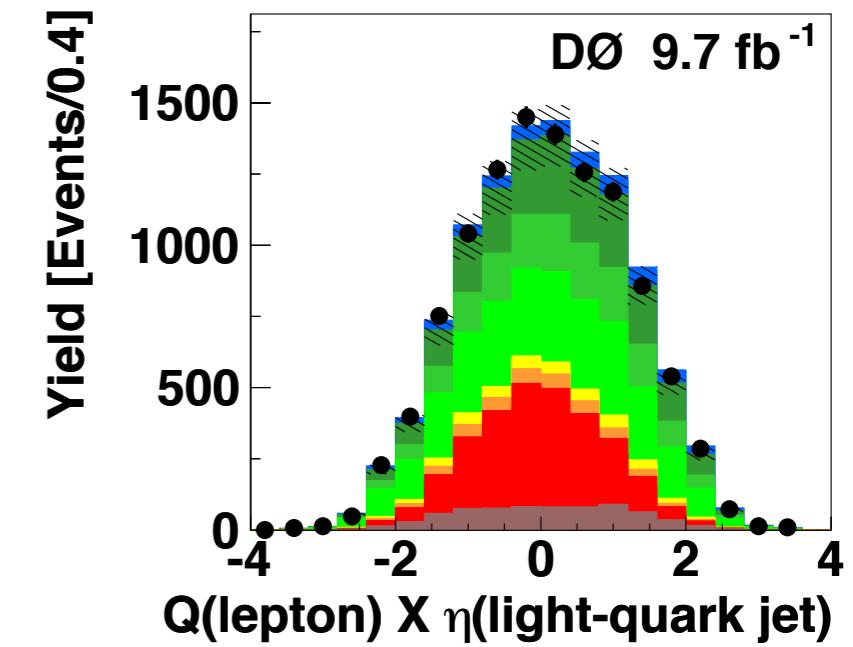
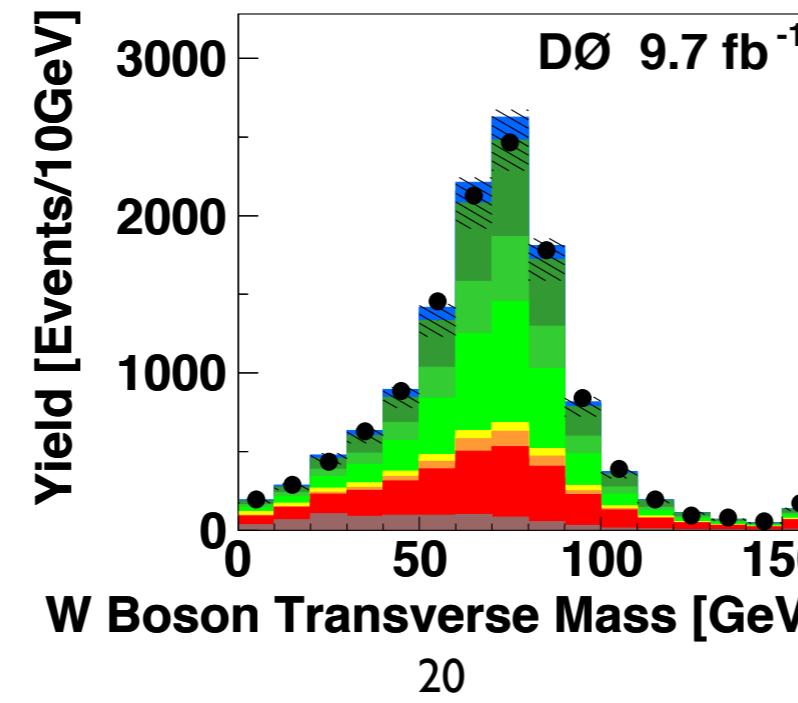
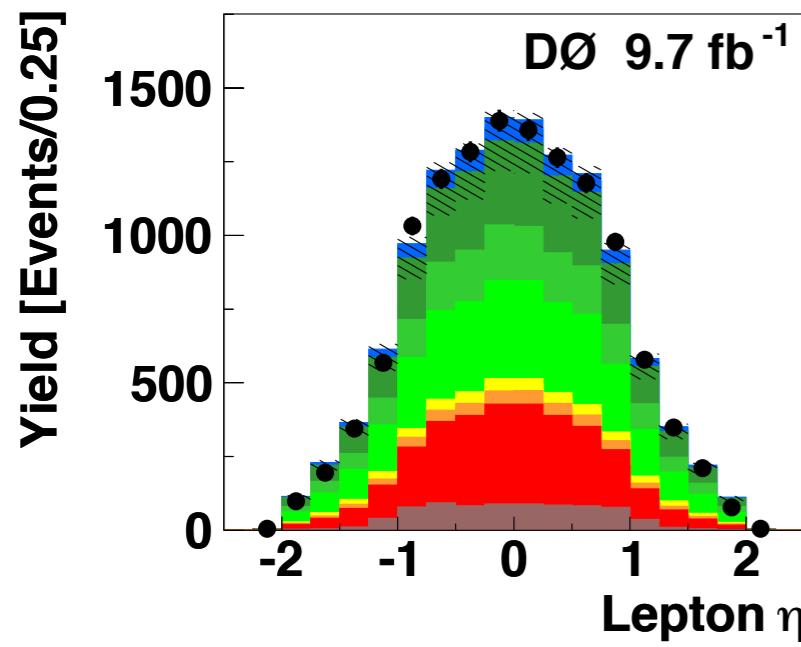
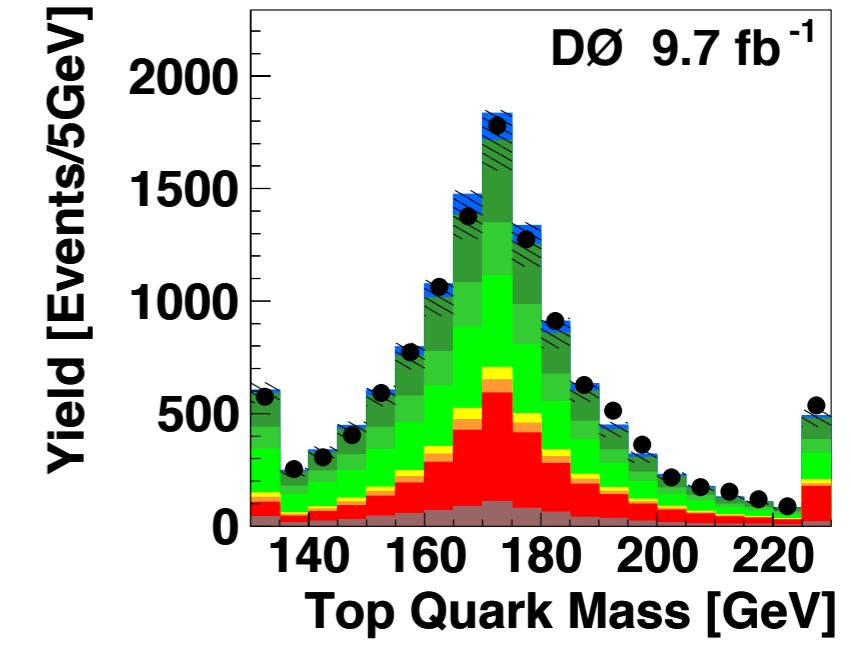
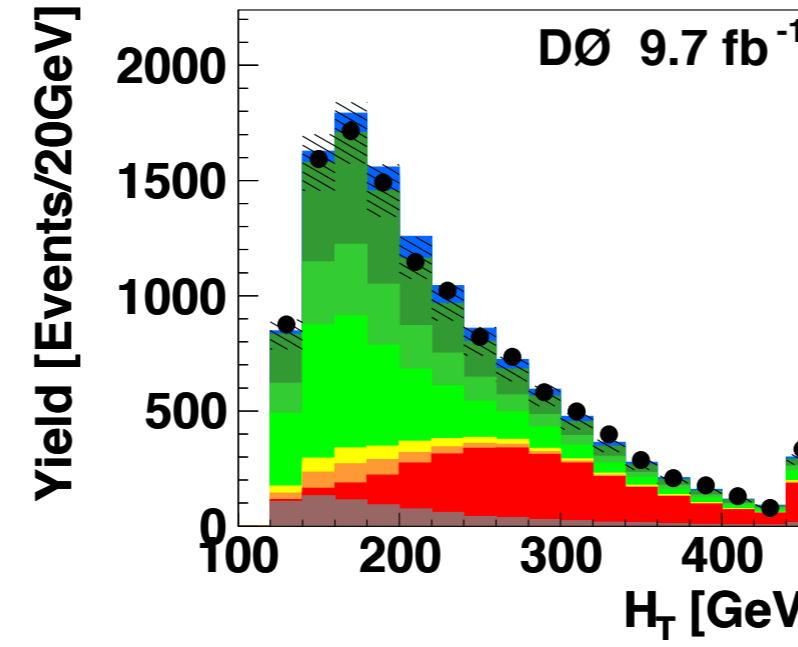
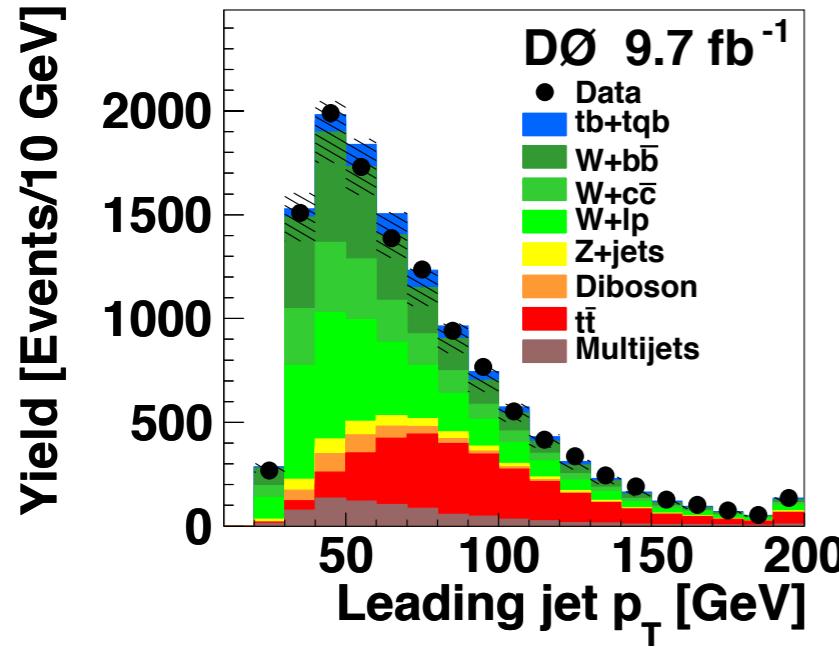


e, μ 2, 3-jets 1, 2 b-tags combined	
<i>tb</i>	257 ± 31
<i>tqb</i>	378 ± 53
W+jets	7394 ± 401
diboson, Z+jets	815 ± 71
top pair	2672 ± 284
multijet	789 ± 81
Total background	11669 ± 503
Data	12103 ± 110

tb: *tqb*: B = 1: 1.5: 45

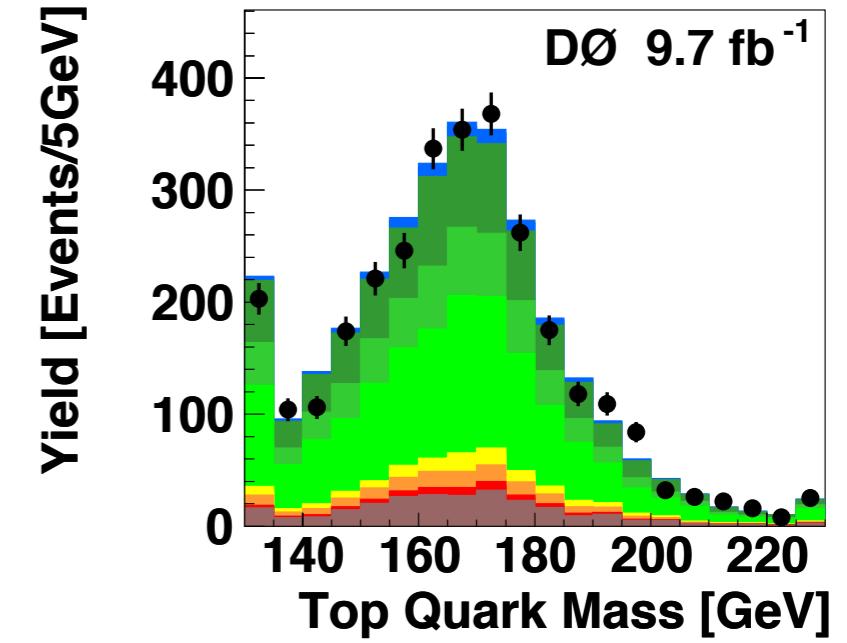
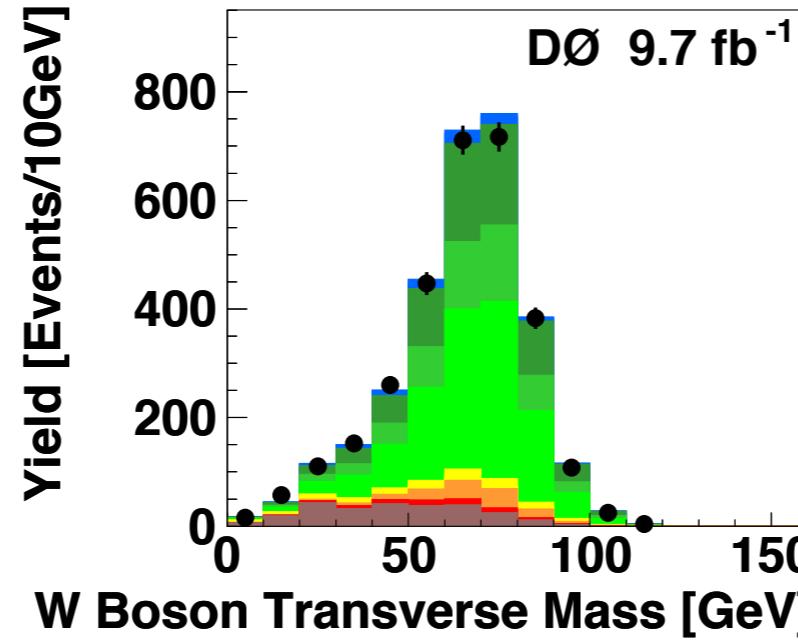
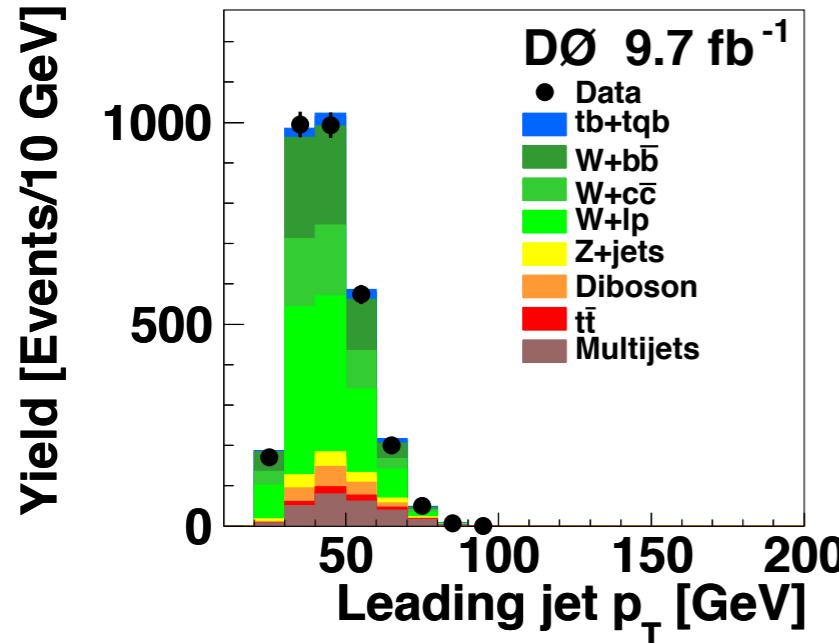


Data-Simulation Comparison

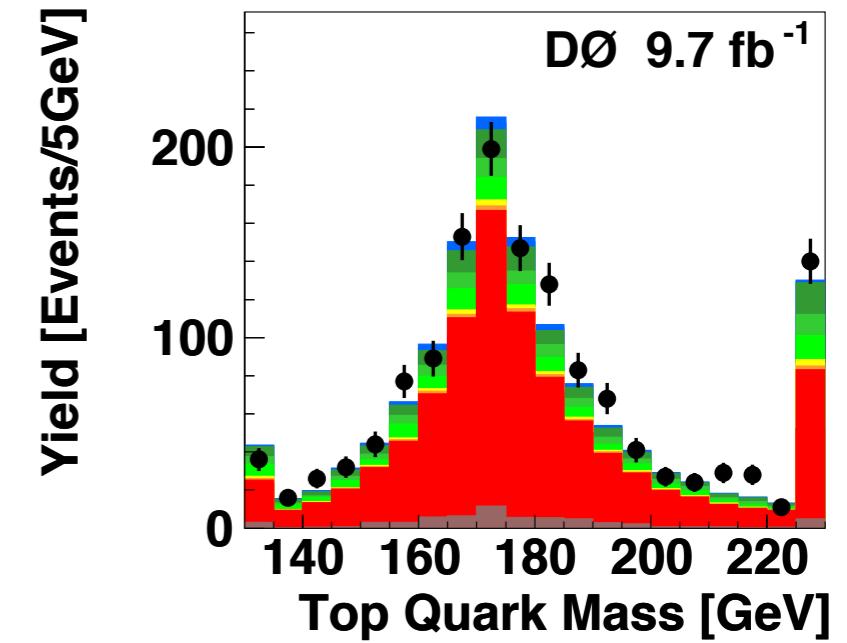
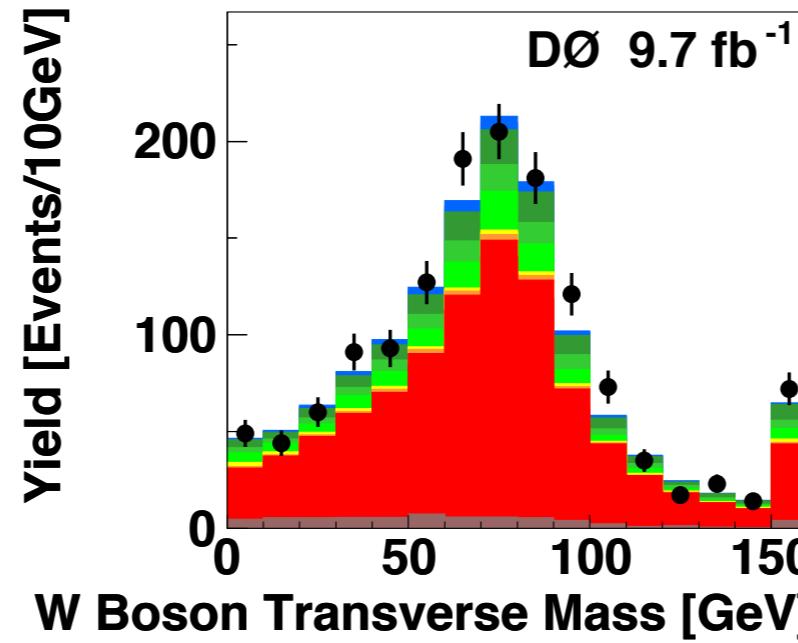
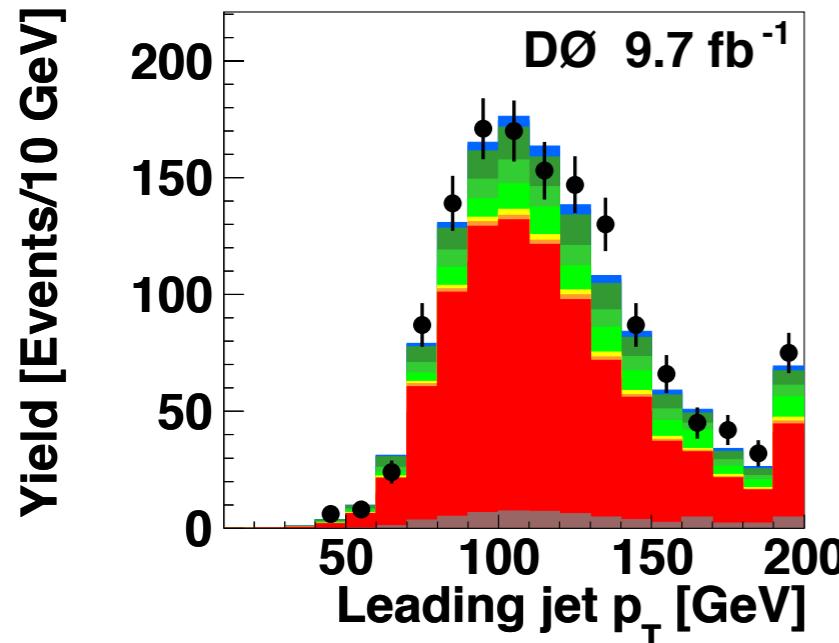


Cross-Check Samples

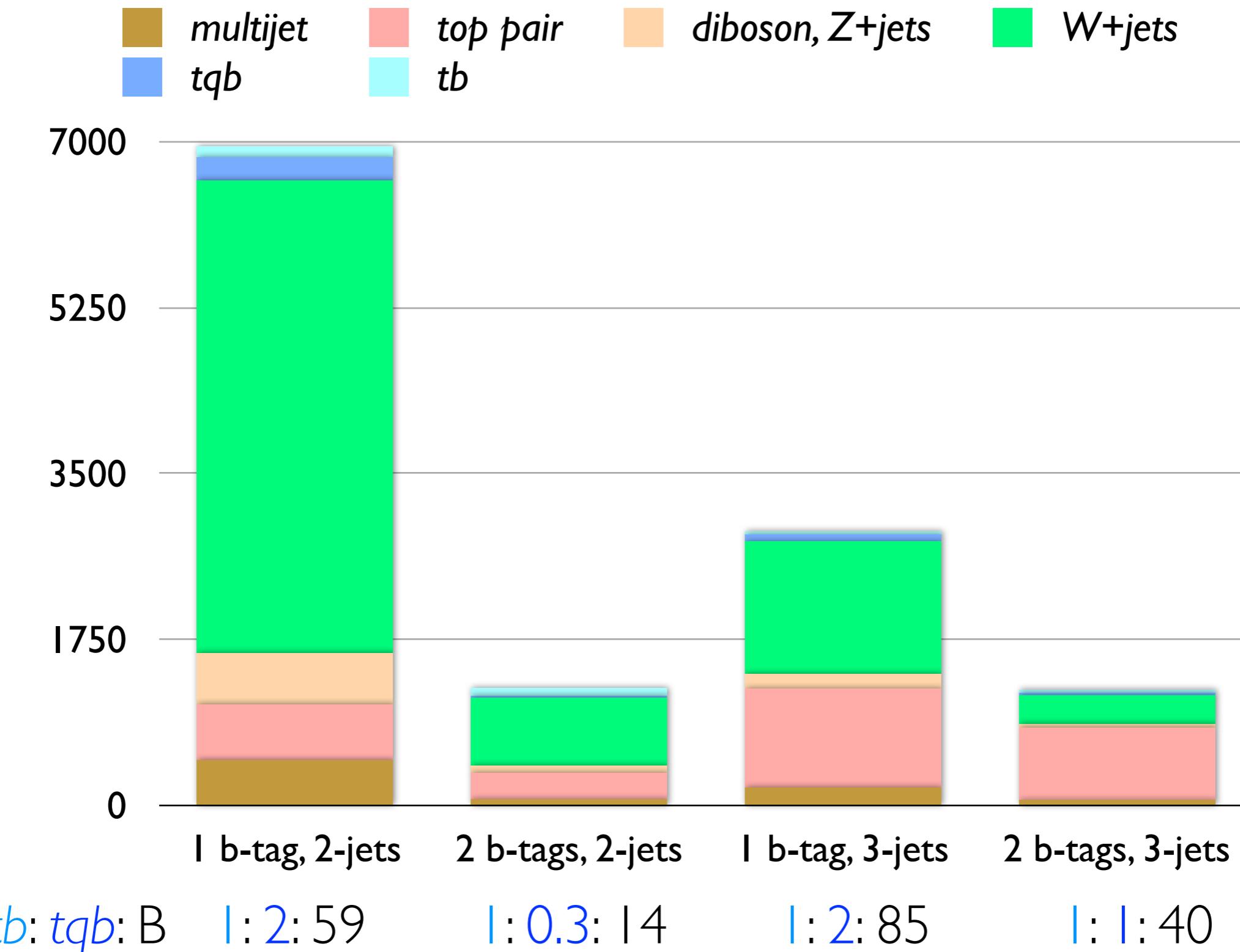
- $W+jets$ enriched sample: 1 b -tag, 2 jets, $H_T < 175$ GeV



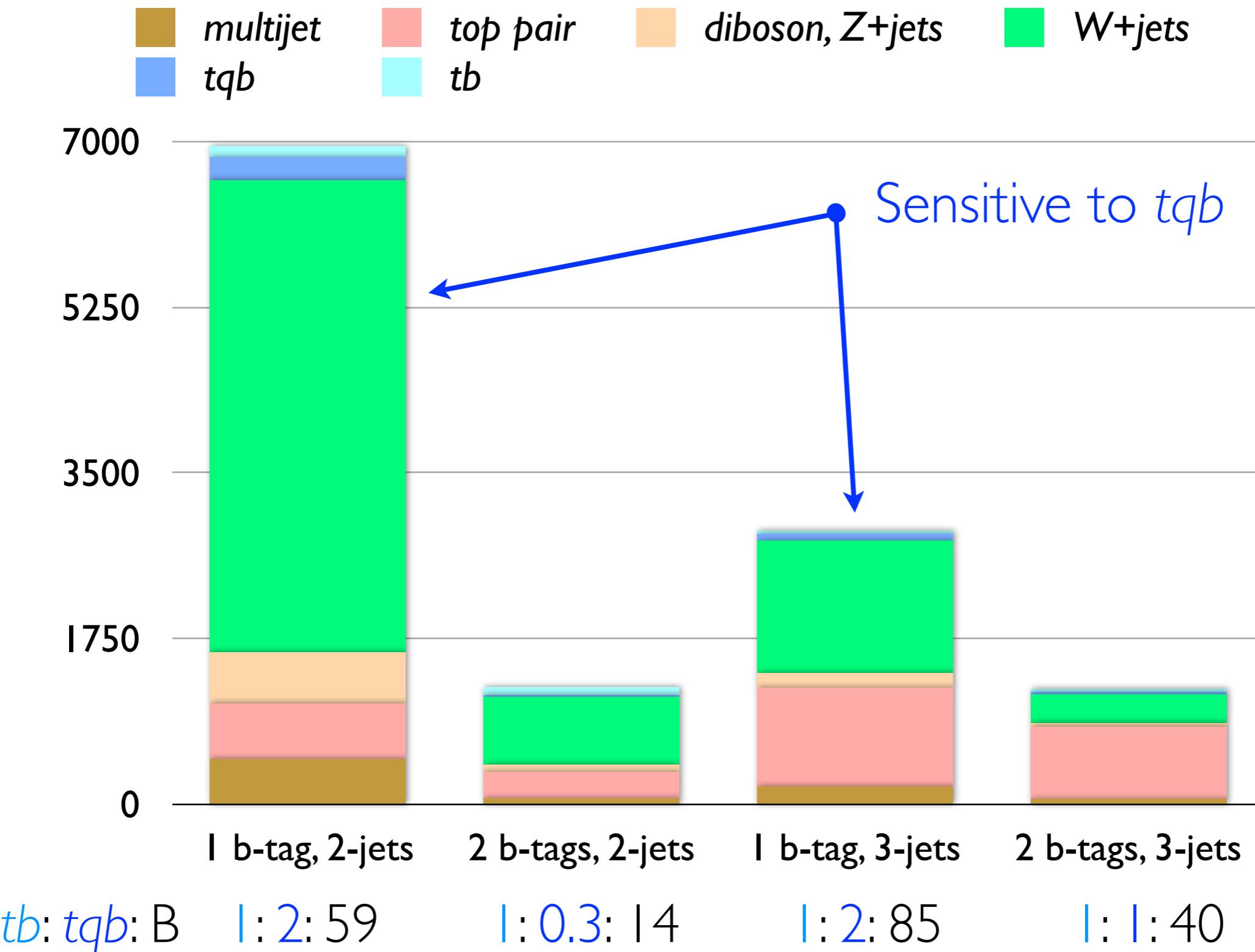
- top pair enriched sample: at least 1 b -tag, 3 jets, $H_T > 300$ GeV



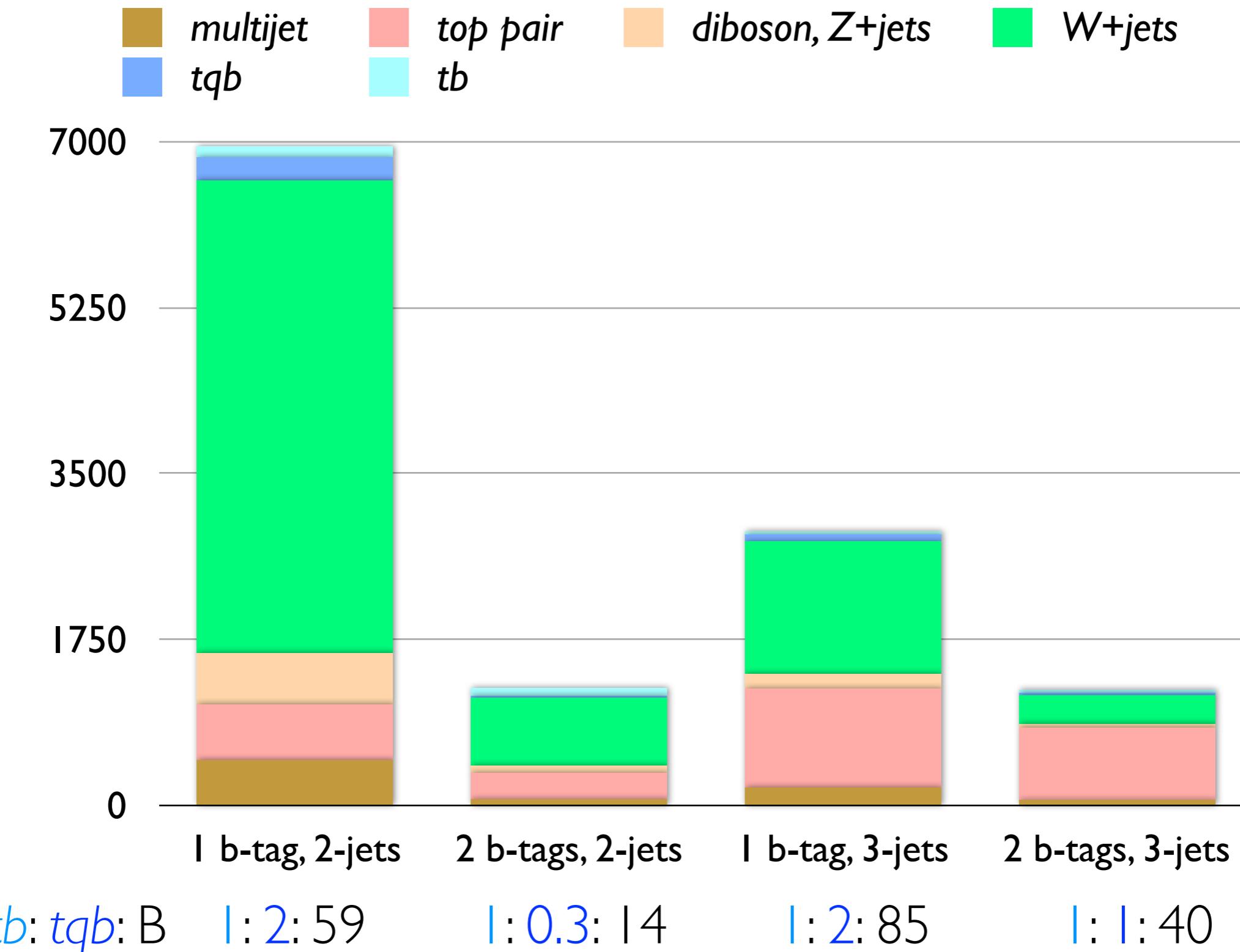
Background Contributions



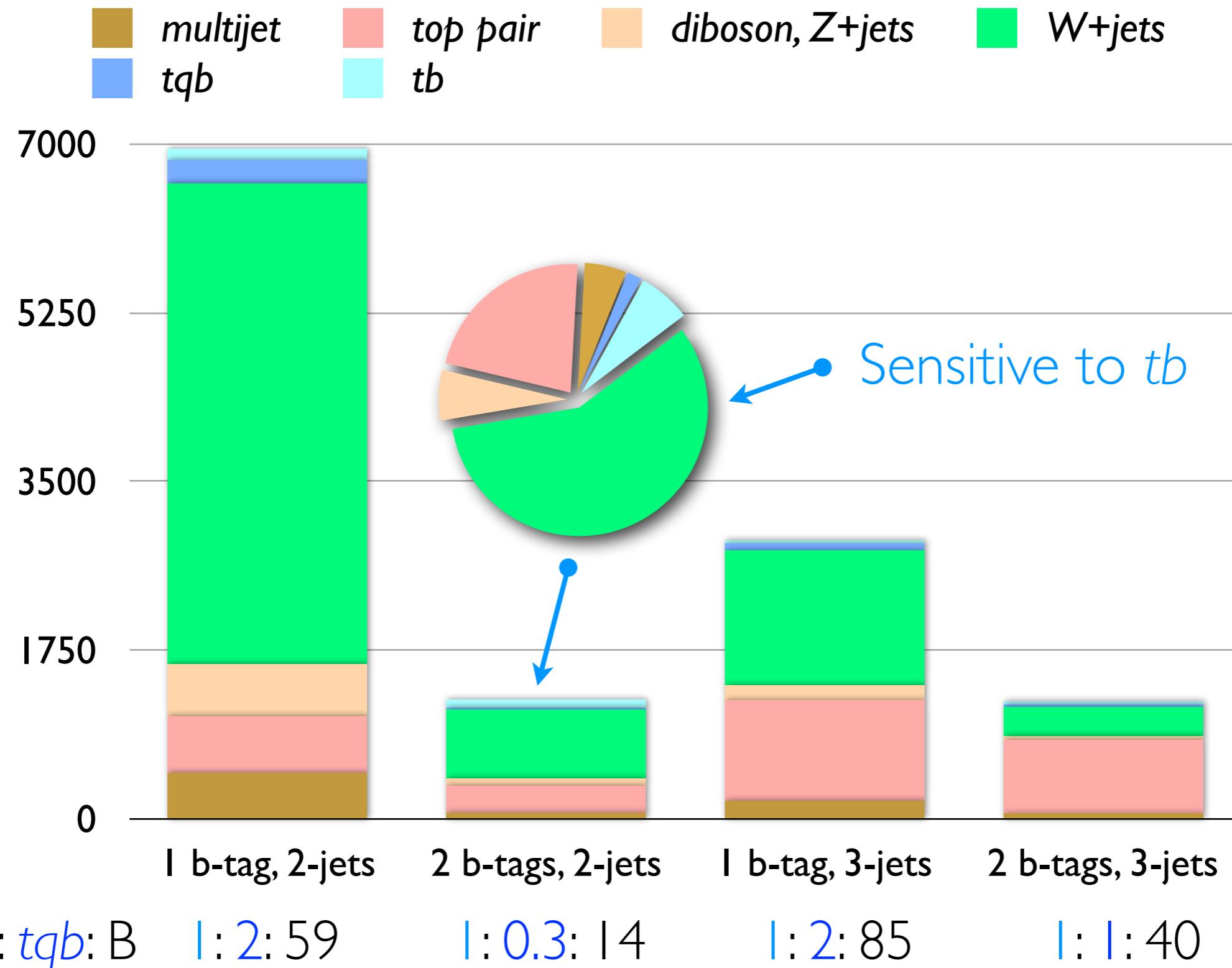
Background Contributions



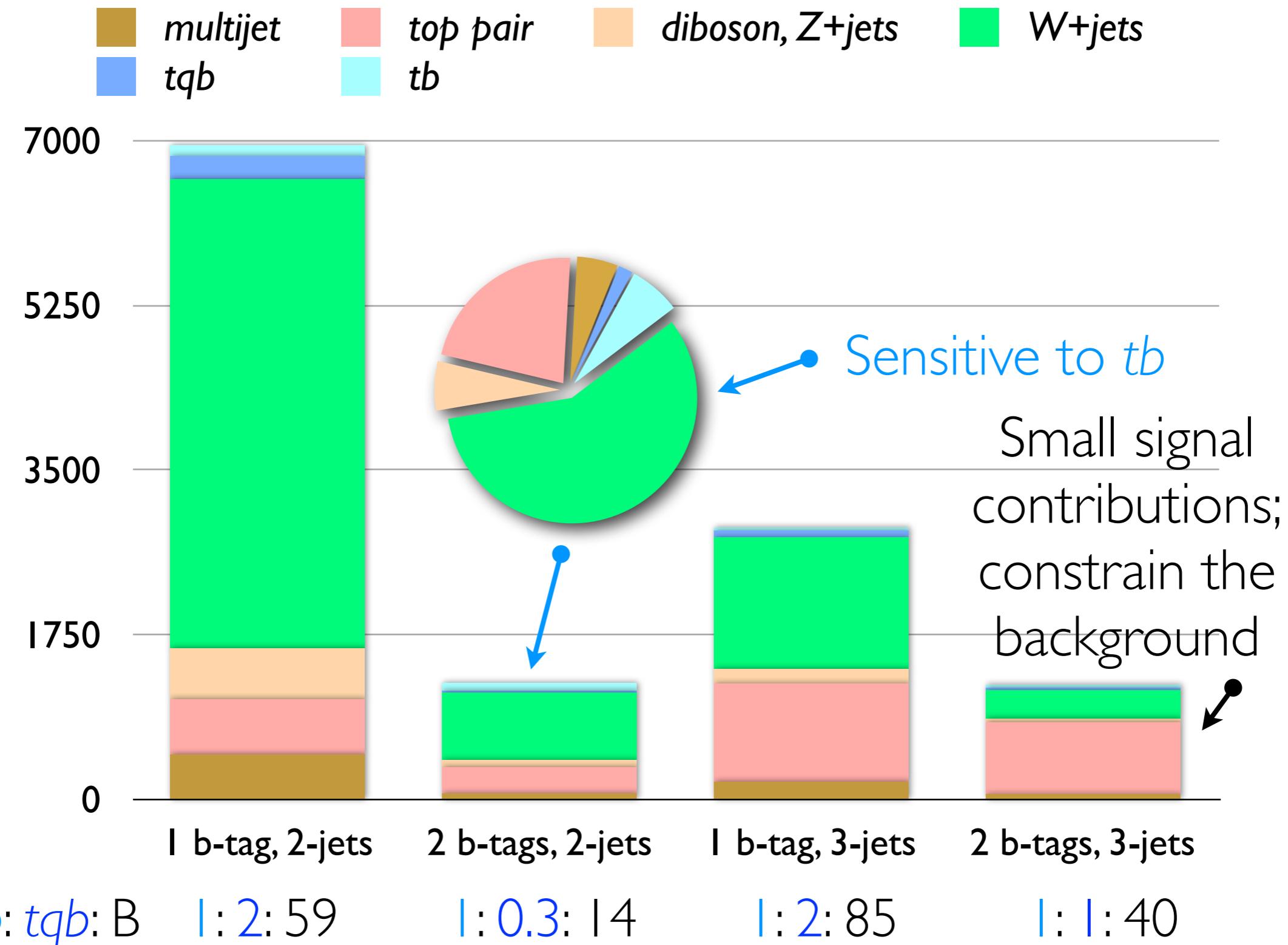
Background Contributions



Background Contributions

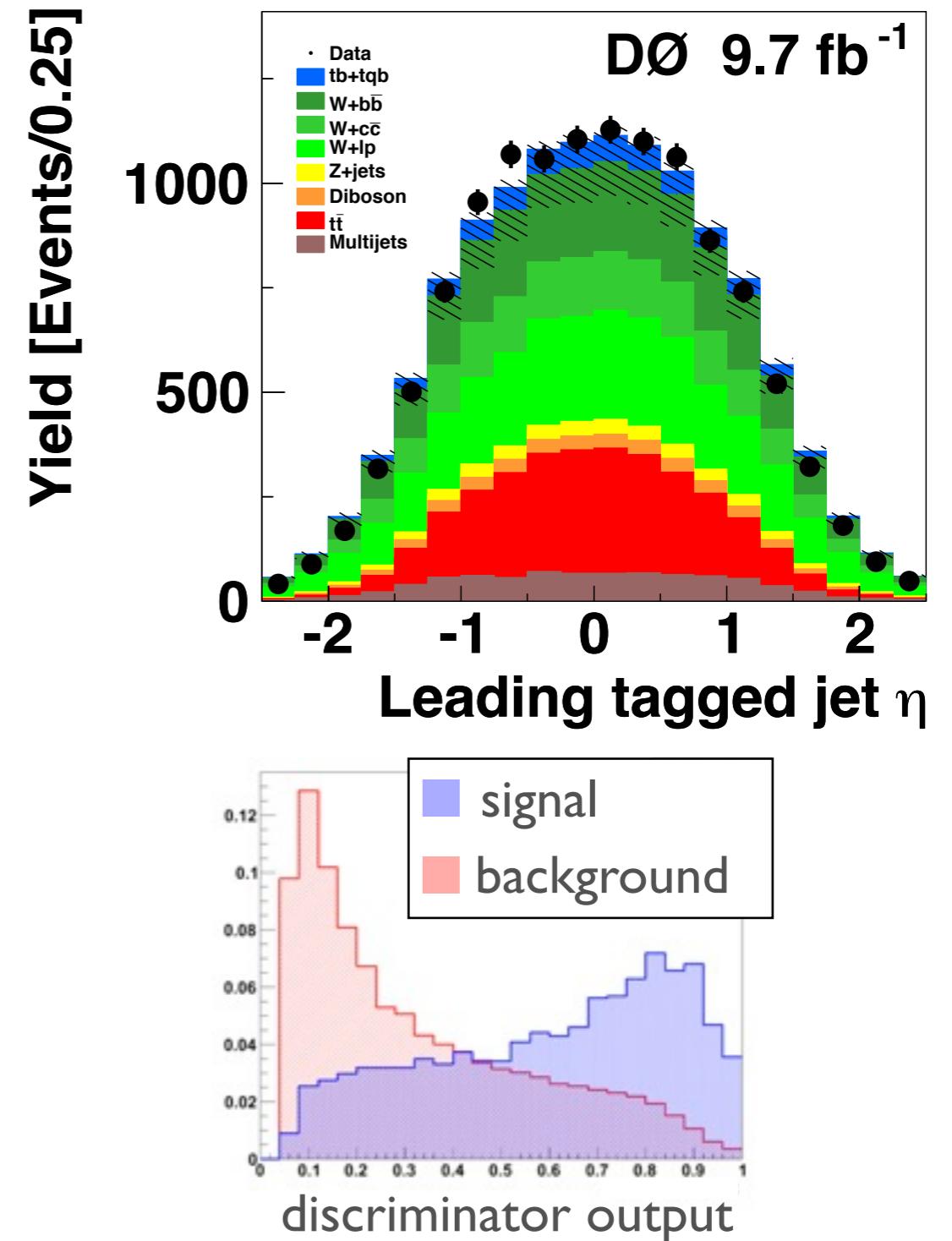


Background Contributions



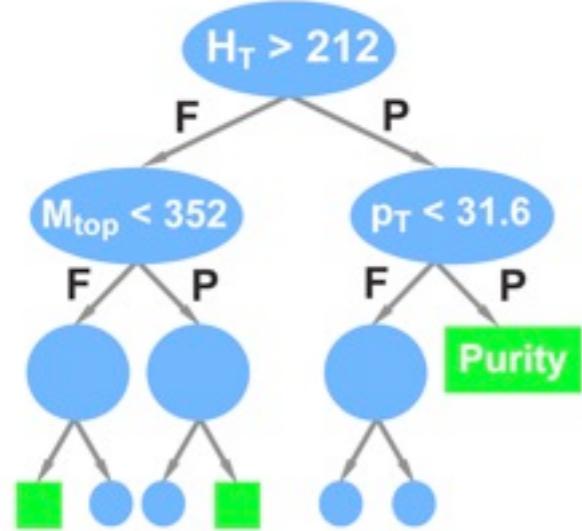
Not A Counting Experiment

- The amount of signal is less than the uncertainty on the backgrounds
- Not feasible to perform a counting experiment
- Need a variable to separate the signals and backgrounds
- No single kinematic or topological variable is sufficient
- Need a multivariate method

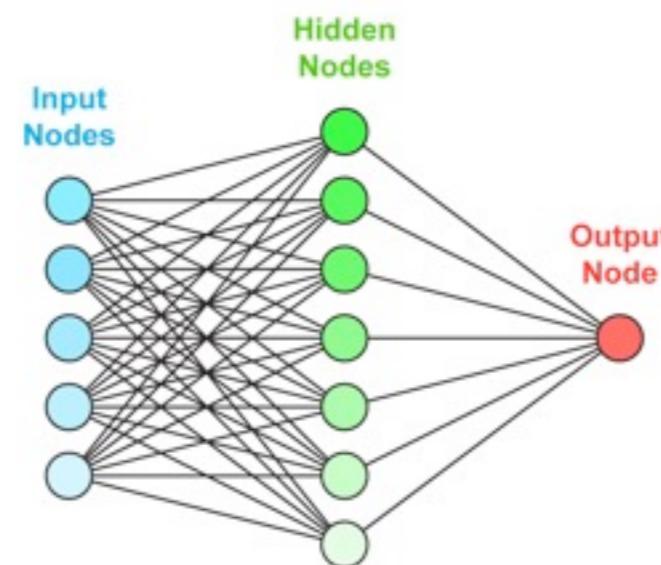


Multivariate Techniques

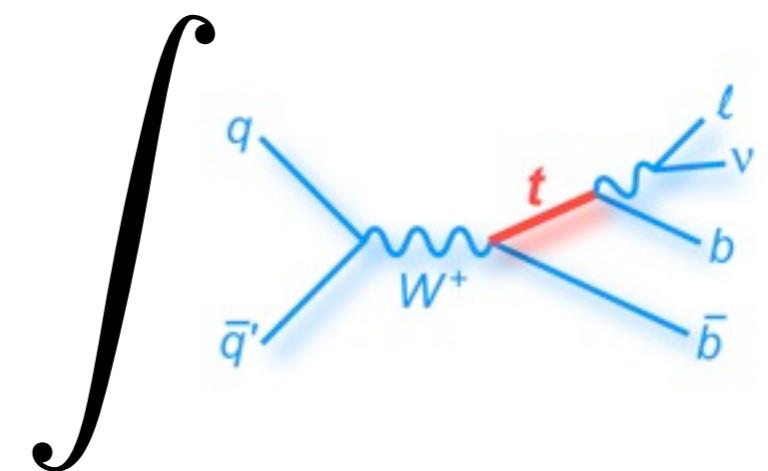
BDT



BNN

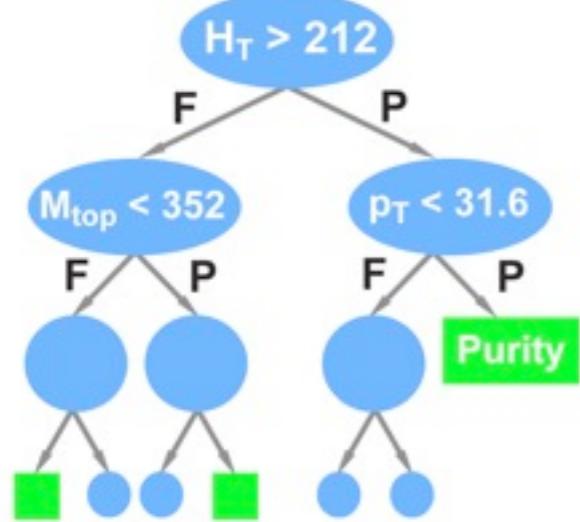


ME

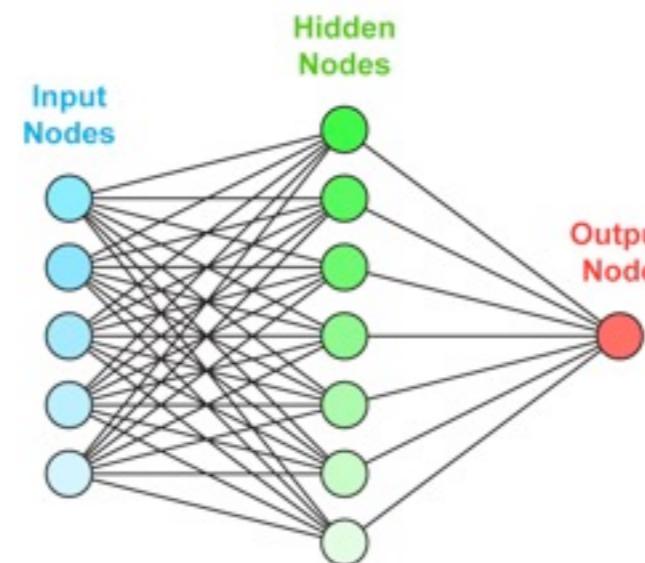


Multivariate Techniques

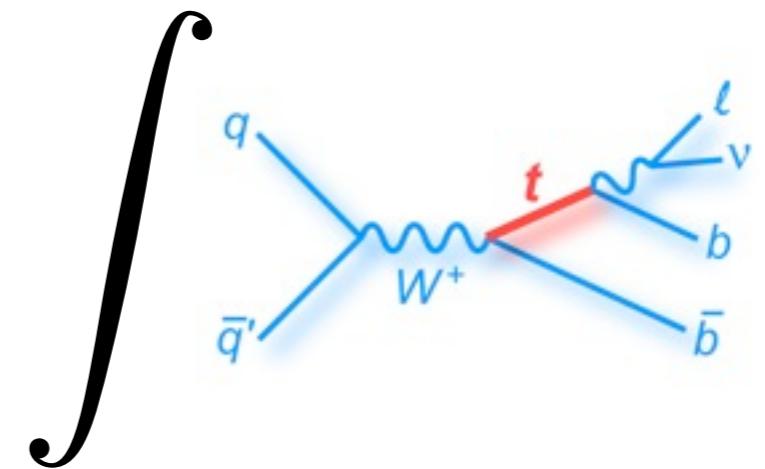
BDT



BNN



ME

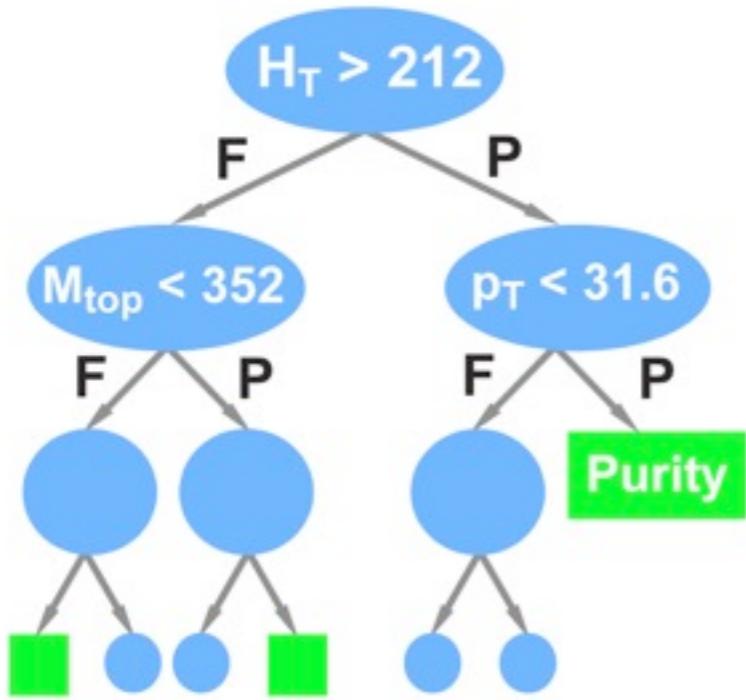


- Machine learning technique
- Use well-described variables ($KS>0.25$) as the input
- Train tb and tqb individually 1/4 MC for training, 1/2 measurement
- Form tb and tqb discriminants

- Calculate probabilities
- Form tb and tqb likelihood ratios
- Less correlated with the others

Boosted Decision Tree

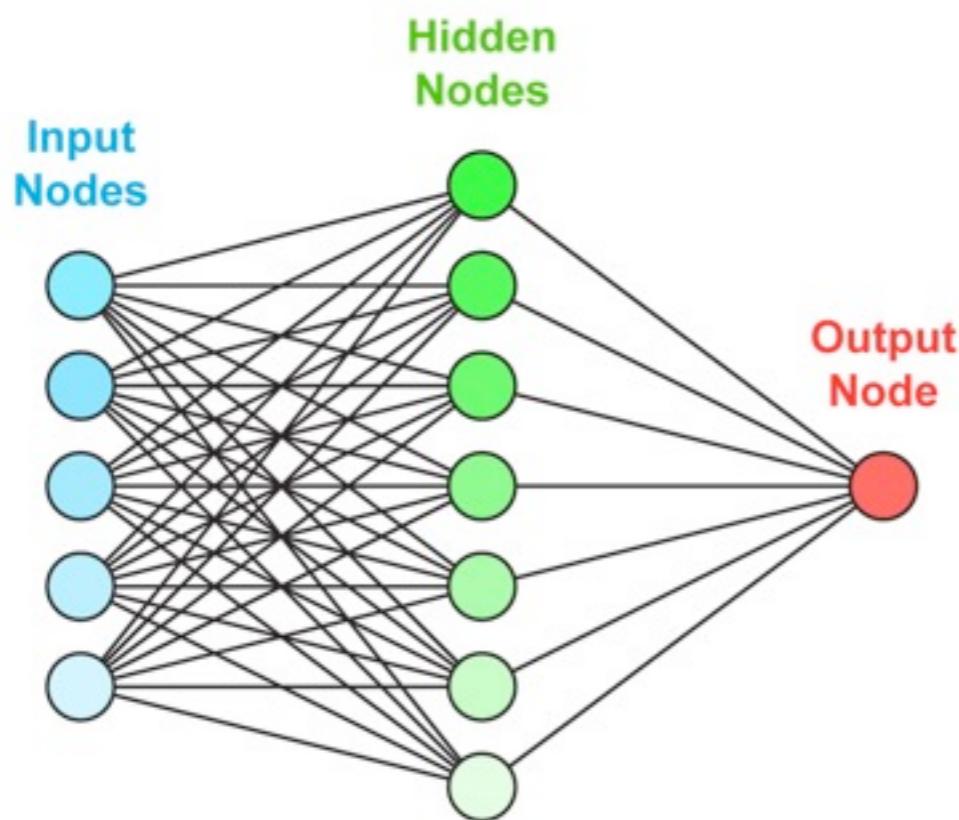
- Apply sequential cuts but keep the failing events
- Train another tree produced by enhancing misclassified events (boosting)
- Average multiple trees and boost the performance
- Up to 30 variables



#	BDT input variables
1	\cancel{E}_T
2	$p_T(\ell)$
3	$\eta(\ell)$
4	$M(\text{jet1})$
5	$p_T(\text{untag1})$
6	$E(\text{untag1})$
7	$M(\text{untag1})$
8	$b_{\text{ID}}(\text{untag1})$
9	$p_T(\text{jet2})$
10	$b_{\text{ID}}(\text{tag1})$
11	$\Delta R(\text{jet1}, \text{jet2})$
12	$\Delta R_{\min}(\ell, \text{jet})$
13	$\Delta\Phi(\ell, \cancel{E}_T)$
14	$\Delta\Phi(\text{jet2}, \cancel{E}_T)$
15	$\Delta\Phi(\text{jet1}, \cancel{E}_T)$
16	$Q(\ell) \times \eta(\text{untag1})$
17	$Q(\ell) \times \eta(\text{jet2})$
18	$Q(\ell) \times \eta(\ell)$
19	$Q(\ell) \times \eta(\text{tag1})$
20	$Q(\ell) \times \eta(\text{jet1})$
21	$\cos(\ell, \text{jet2})_{\text{lab}}$
22	$\cos(\ell, \text{jet1})_{\text{lab}}$
23	$H_T(\text{alljets})$
24	$H_T(\ell, \cancel{E}_T, \text{alljets})$
25	$H_T(\ell, \cancel{E}_T)$
26	Centrality(alljets)
27	$M_{\text{jet1}}, \text{jet2}$
28	$p_T(\text{jet1}, \text{jet2})$
29	$M_T(W)$
30	$p_T(W)$

Bayesian Neural Network

- NN produces a **probability** of an event to be produced by signal processes
- Average over many networks and improve the performance



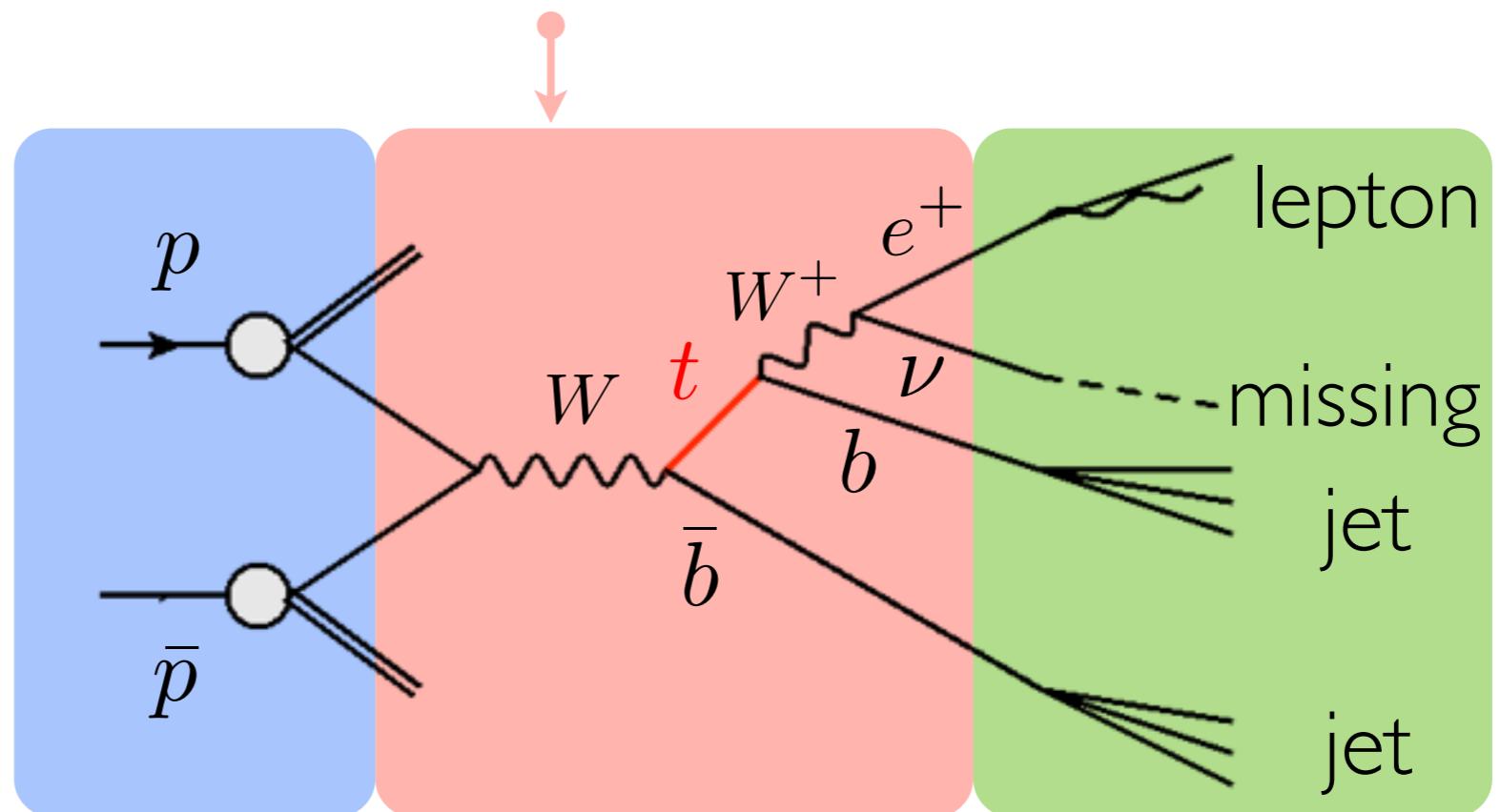
- Up to 21 variables

#	BNN input variables
1	$p_T(\text{tag1})$
2	$\eta(\text{tag1})$
3	$\Delta\Phi(\ell, \text{tag1})$
4	$b_{\text{ID}}(\text{tag1})$
5	$p_T(\text{untag1})$
6	$\eta(\text{untag1})$
7	$\Delta\Phi(\ell, \text{untag1})$
8	$b_{\text{ID}}(\text{untag1})$
9	$p_T(\ell)$
10	$\eta(\ell)$
11	E_T
12	$\Delta\Phi(\ell, E_T)$
13	$p_T(\text{tag2})$
14	$\eta(\text{tag2})$
15	$\Delta\Phi(\ell, \text{tag2})$
16	$b_{\text{ID}}(\text{tag2})$
17	$p_T(\text{untag2})$
18	$\eta(\text{untag2})$
19	$b_{\text{ID}}(\text{untag2})$
20	$M_T(W)$
21	$Q(\ell) \times \eta(\text{untag1})$

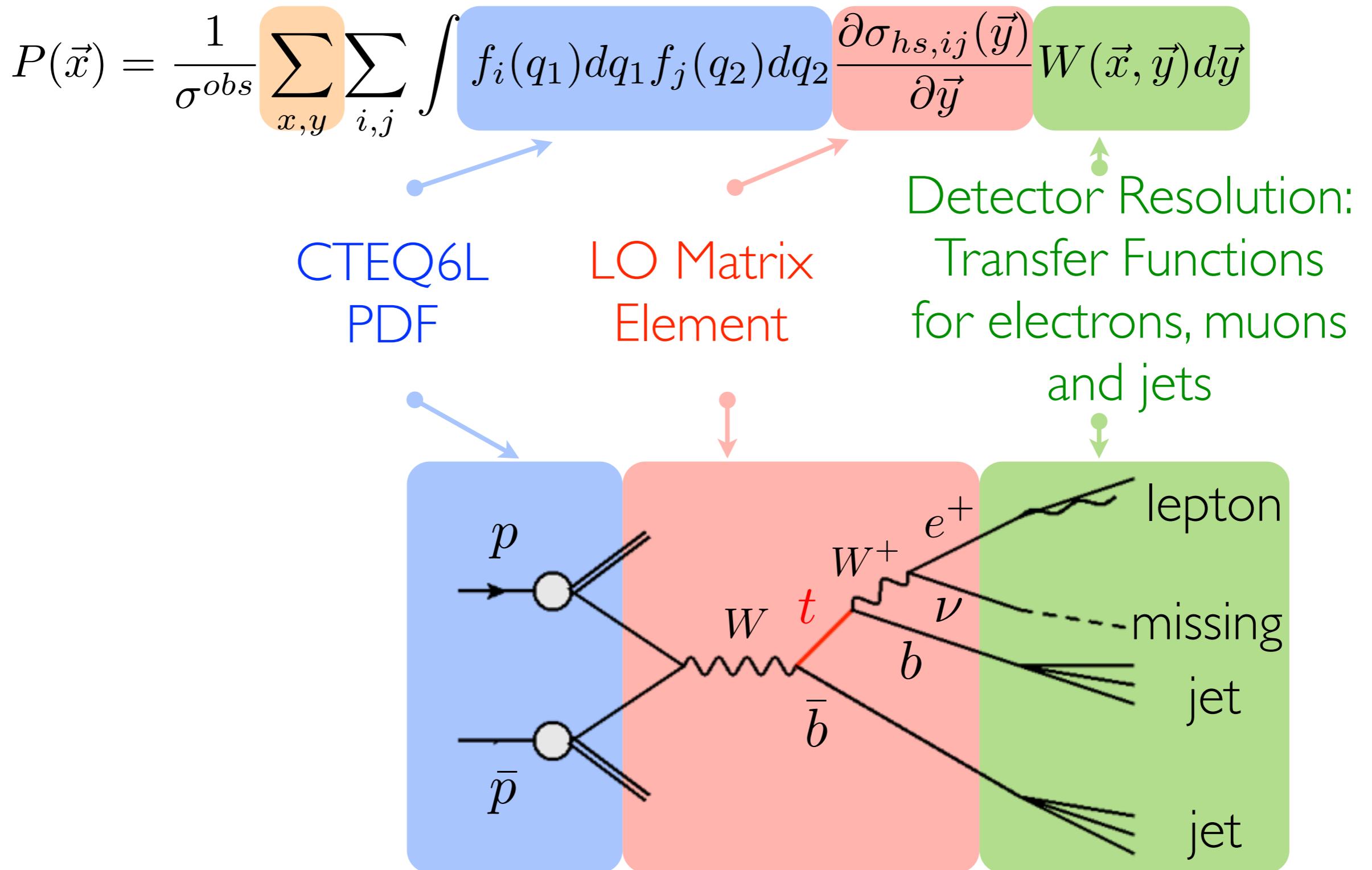
Matrix Element Method

$$P(\vec{x}) = \frac{1}{\sigma^{obs}} \sum_{x,y} \sum_{i,j} \int f_i(q_1) dq_1 f_j(q_2) dq_2 \frac{\partial \sigma_{hs,ij}(\vec{y})}{\partial \vec{y}} W(\vec{x}, \vec{y}) d\vec{y}$$

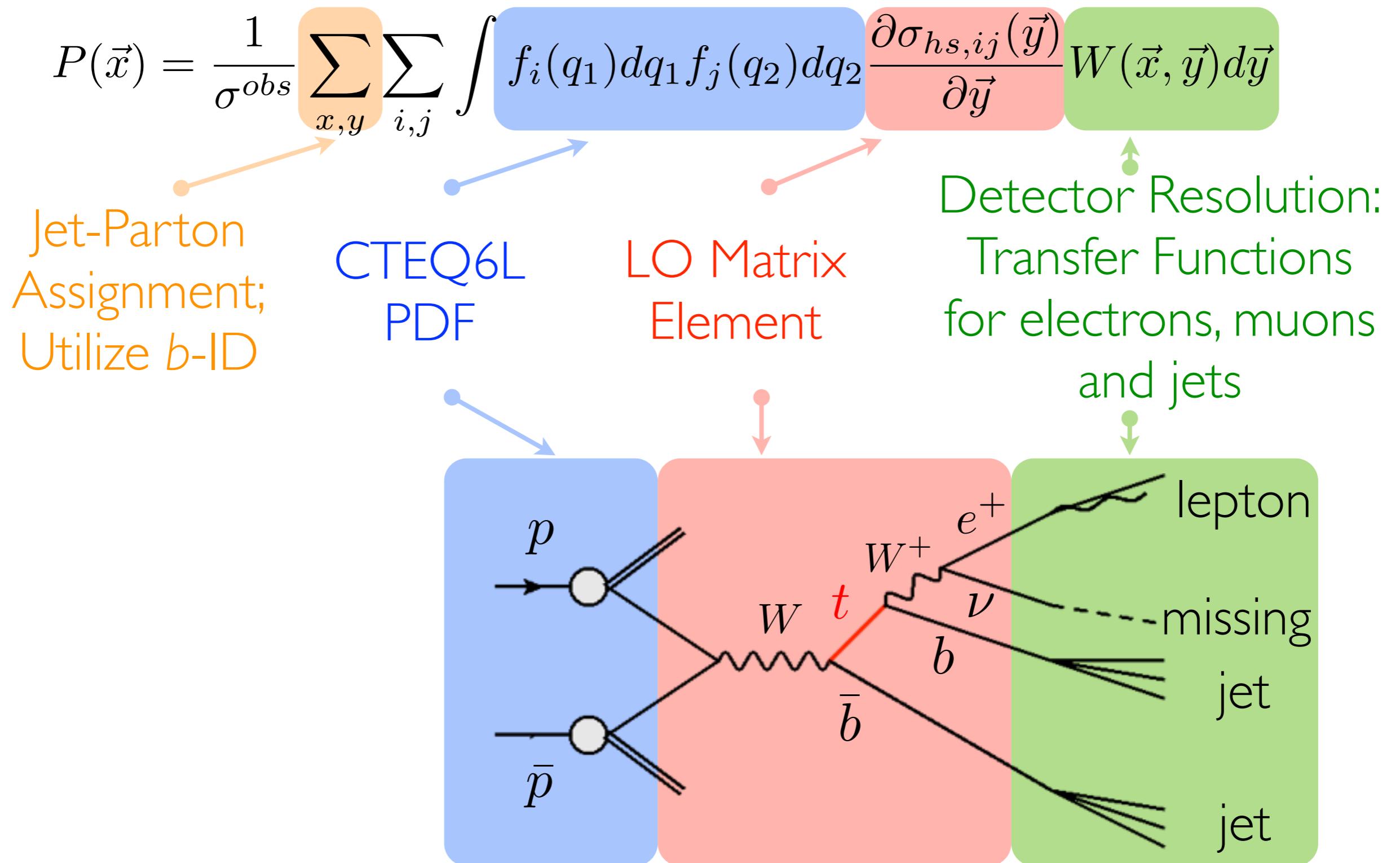
LO Matrix
Element



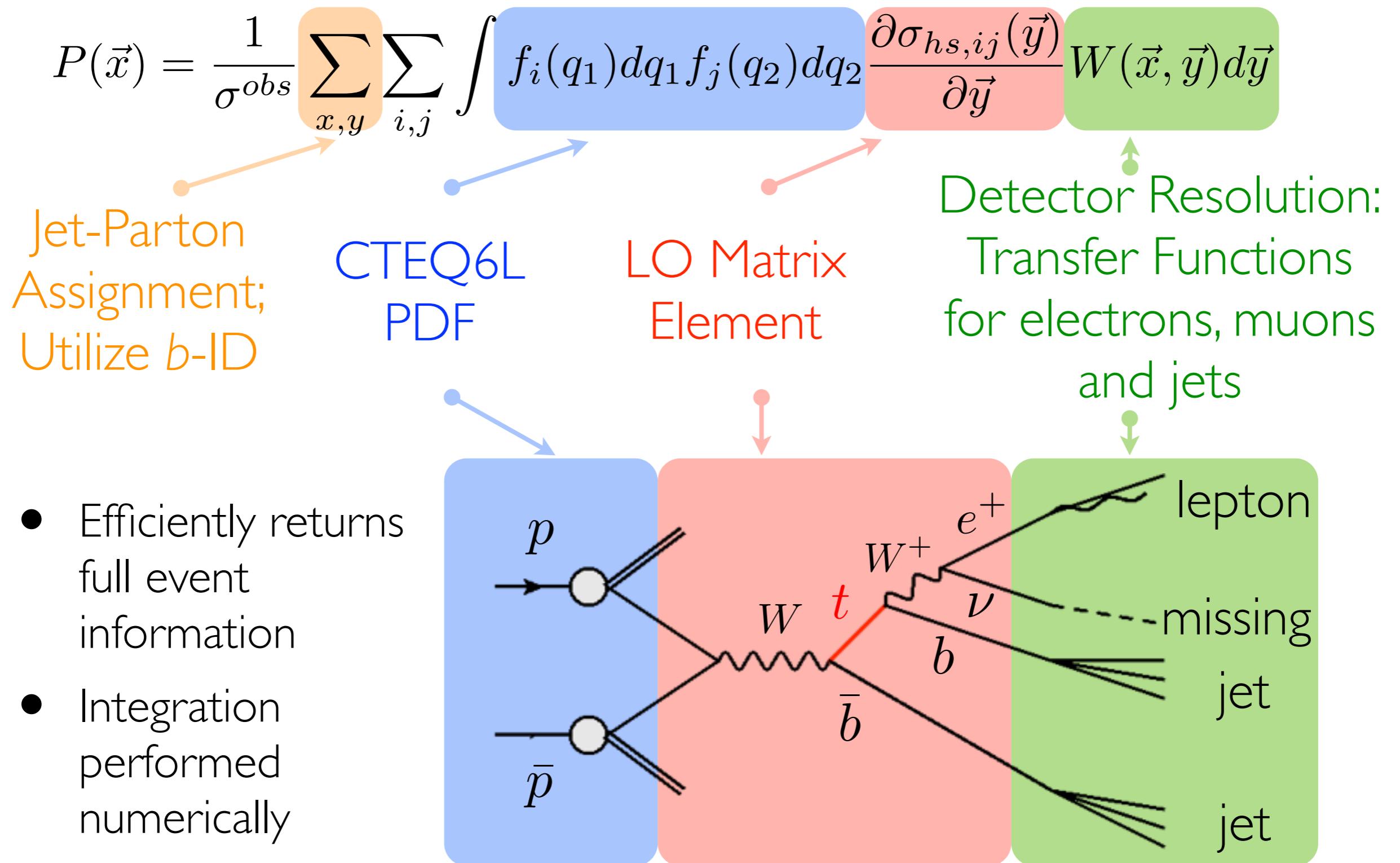
Matrix Element Method



Matrix Element Method



Matrix Element Method



ME Discriminant

- ME Processes:

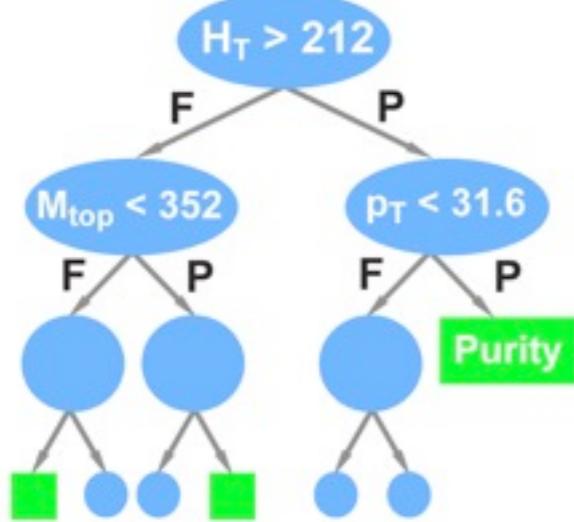
	2 Jet	3 Jet
Single Top	tb, tq	tbg, tqb, tgg
Background	$Wbb, Wcg, Wgg,$ <i>top pair, WW, WZ, ggg</i>	$Wbbg, Wugg,$ <i>top pair</i>

- Discriminant: Likelihood ratio
 - b -ID output information included (NEW)

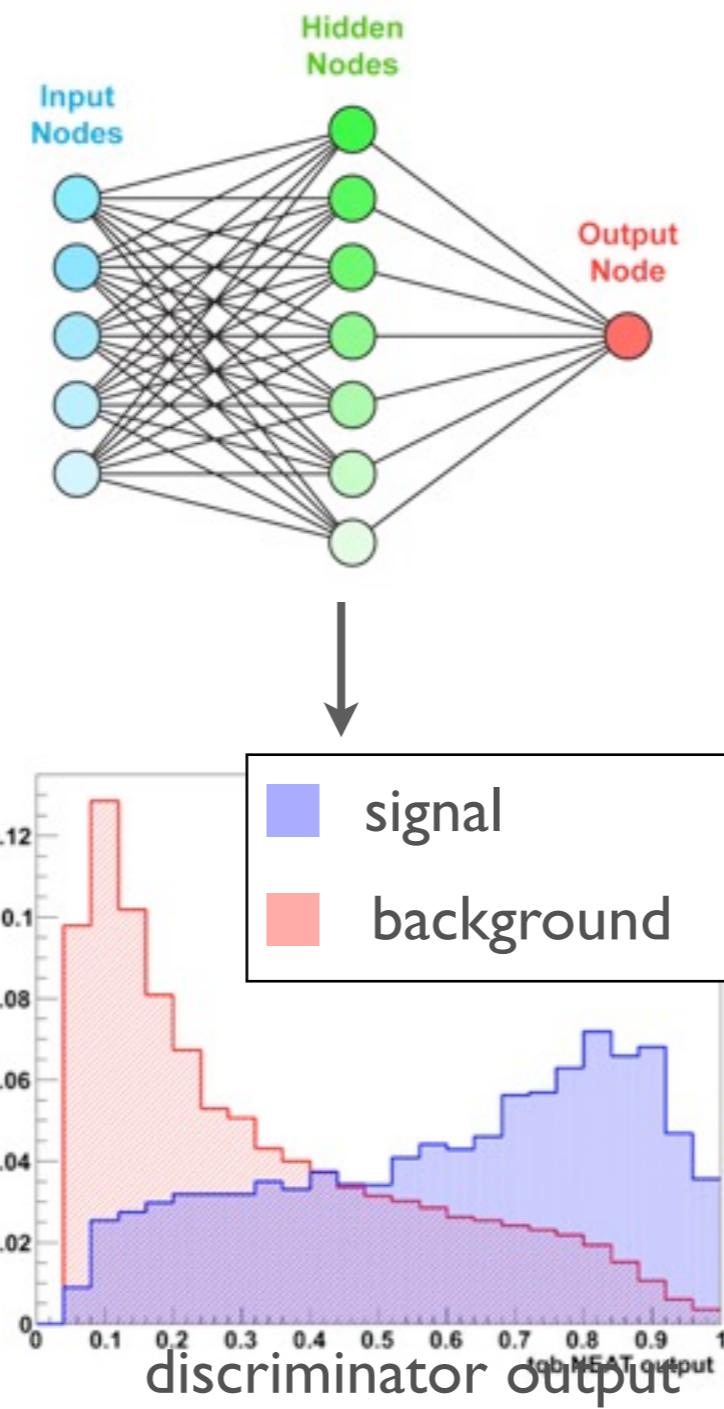
$$D(x) = \frac{P_{sig}(x)}{P_{sig}(x) + P_{bkgd}(x)}$$

BNN Combination

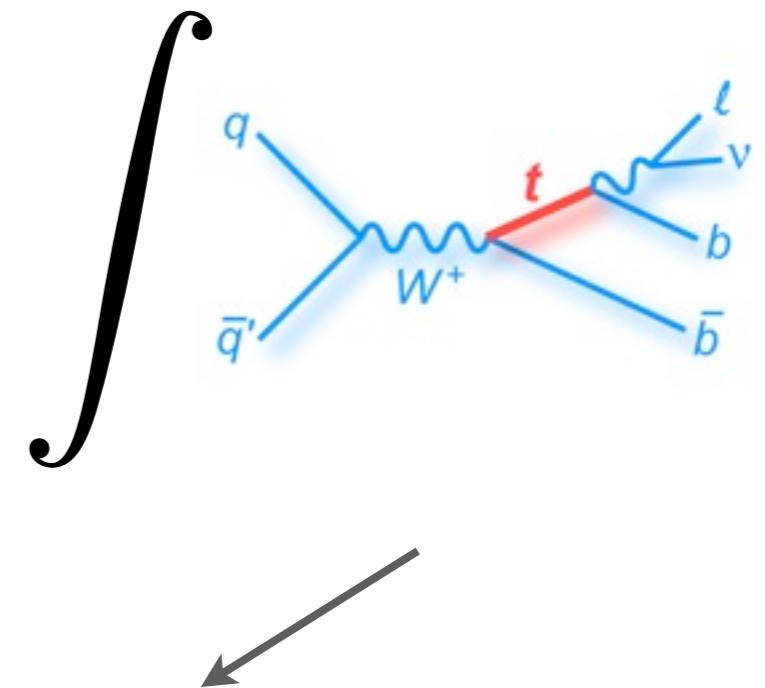
BDT



BNN



ME

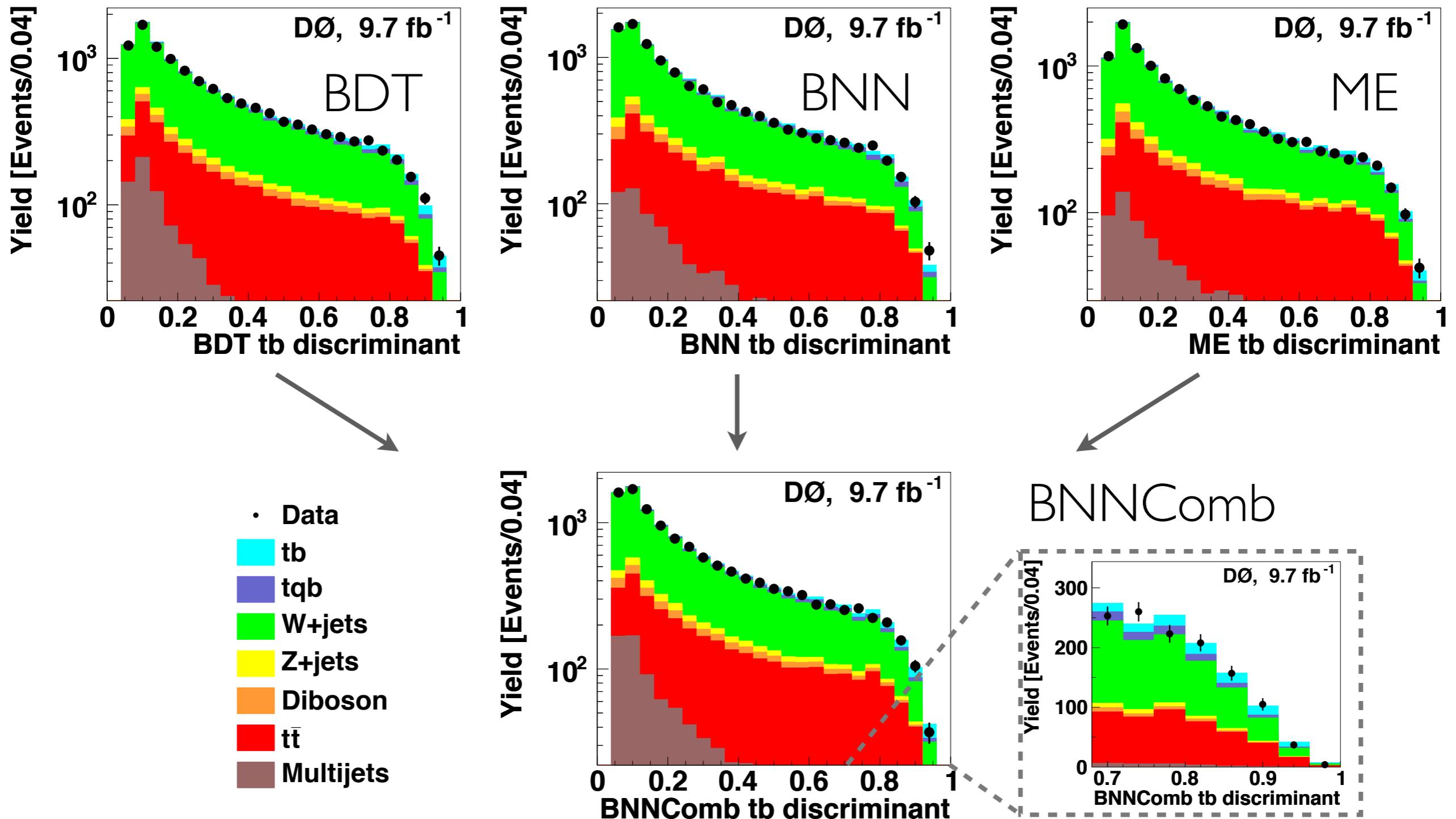


Use BNN to
combine the 3
methods

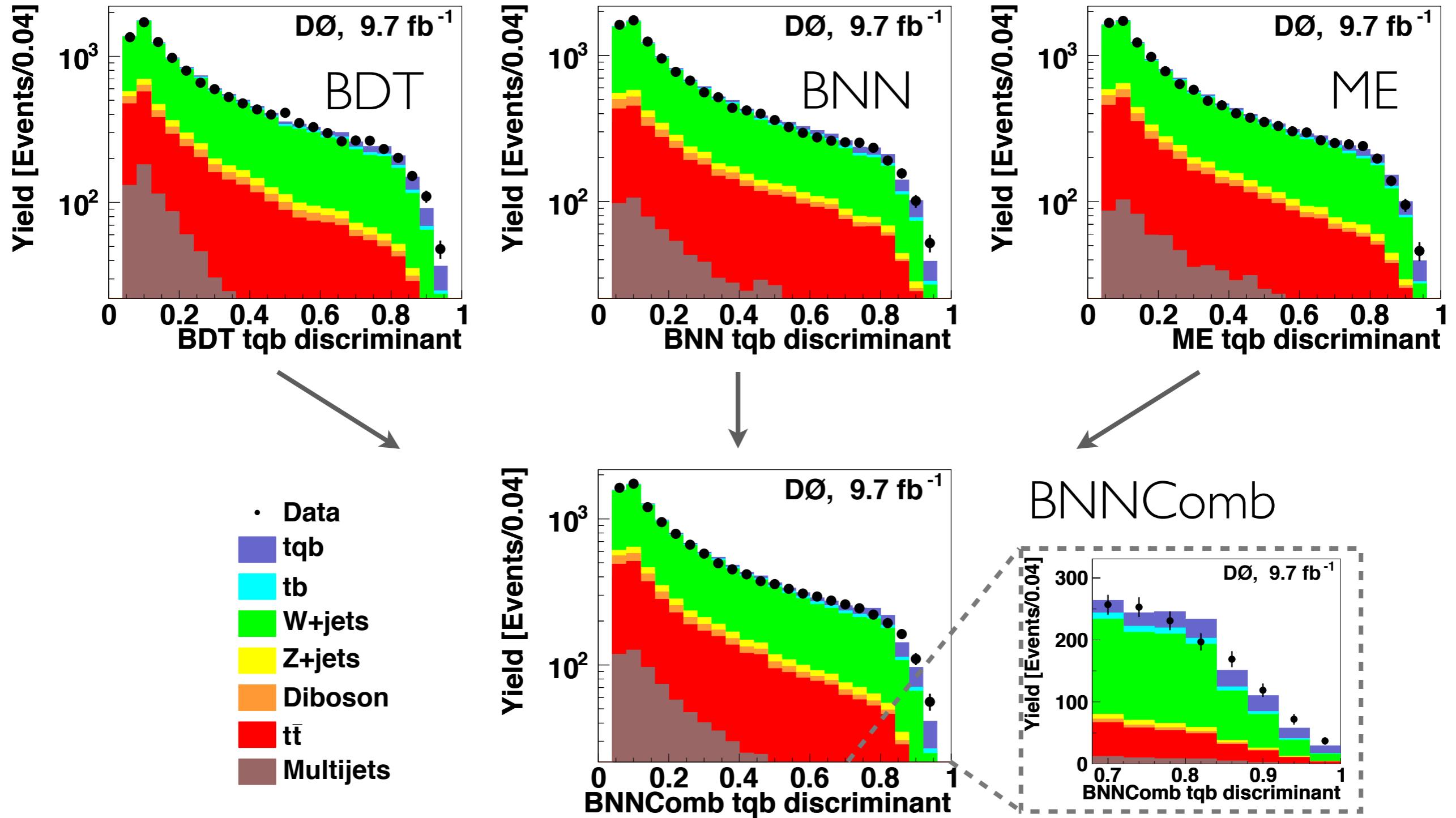
Correlations

BDT
77%
↔
BNN
↔
ME
75%
73%

BNN tb Combination

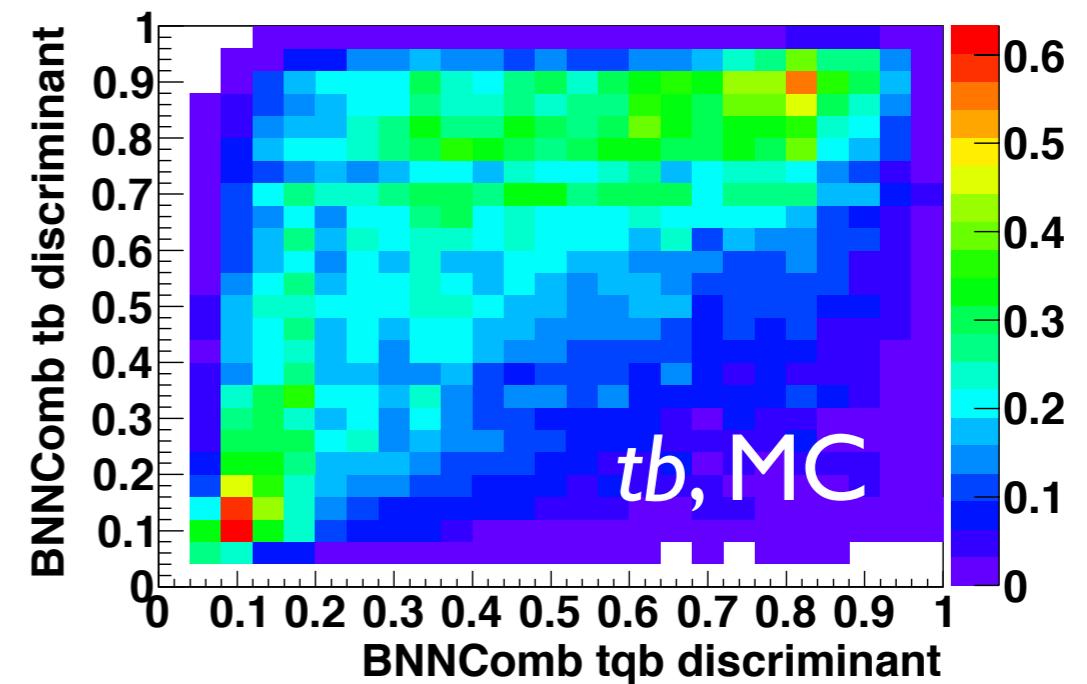
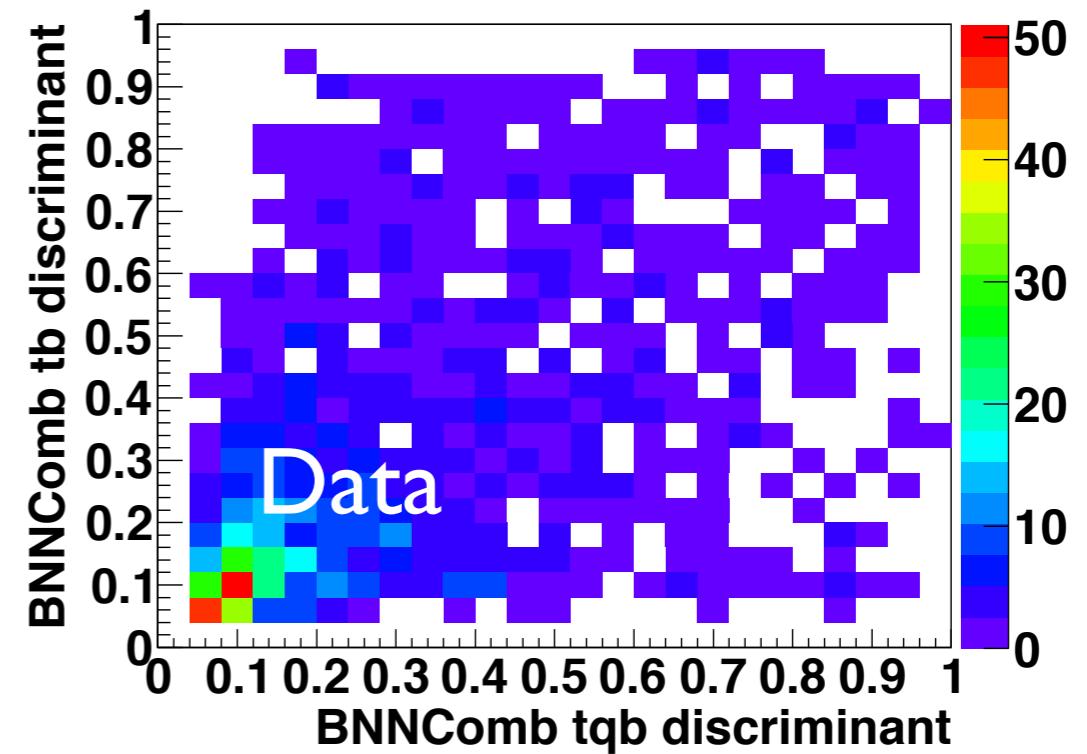


BNN tqb Combination



New Discriminant

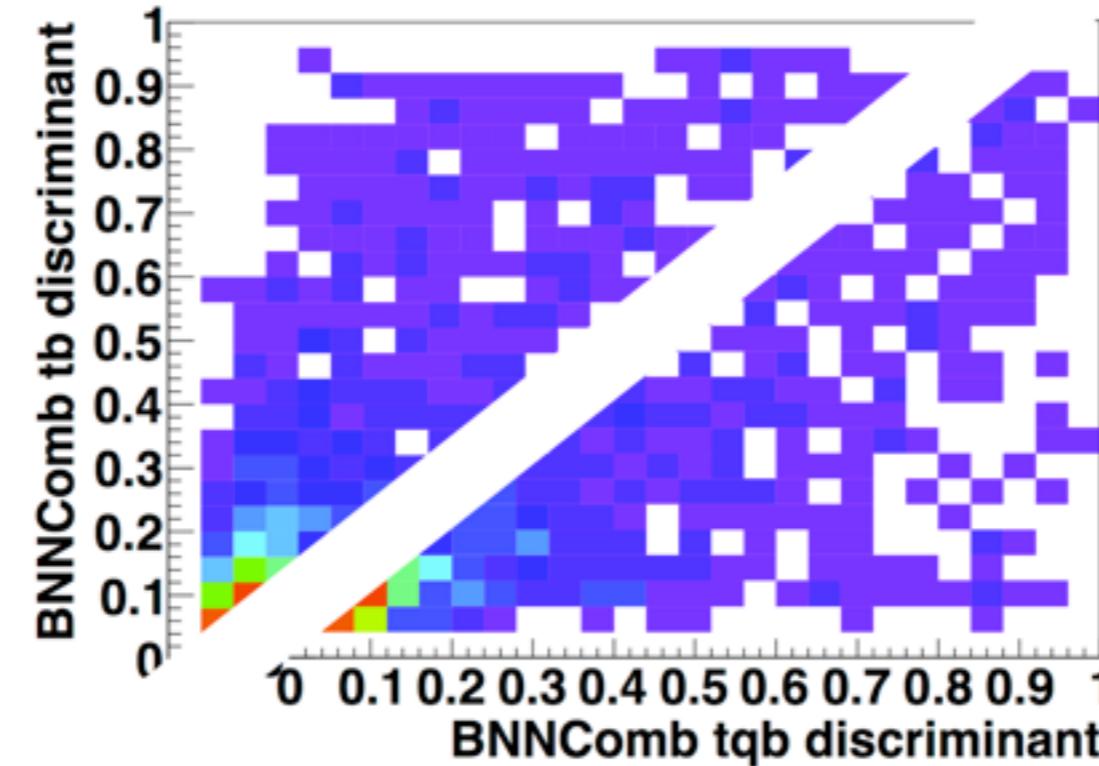
- Aim to simultaneously measure tb and tqb signals without assuming the SM prediction for either
- At a first step, use a discriminant sensitive to both signals
- Ensure each bin containing enough statistics to have a stable measurement



New Discriminant

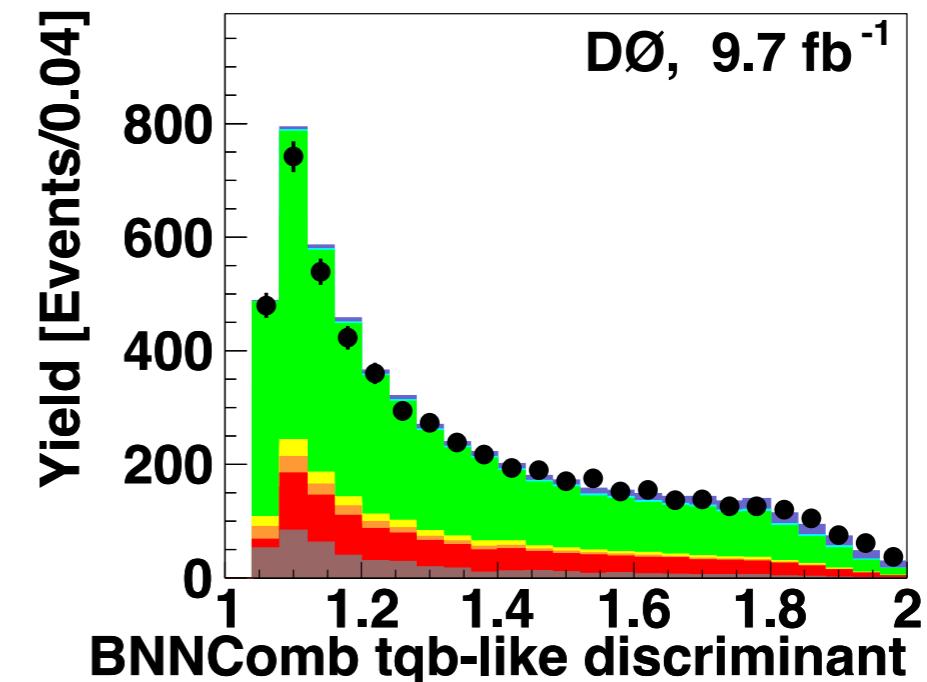
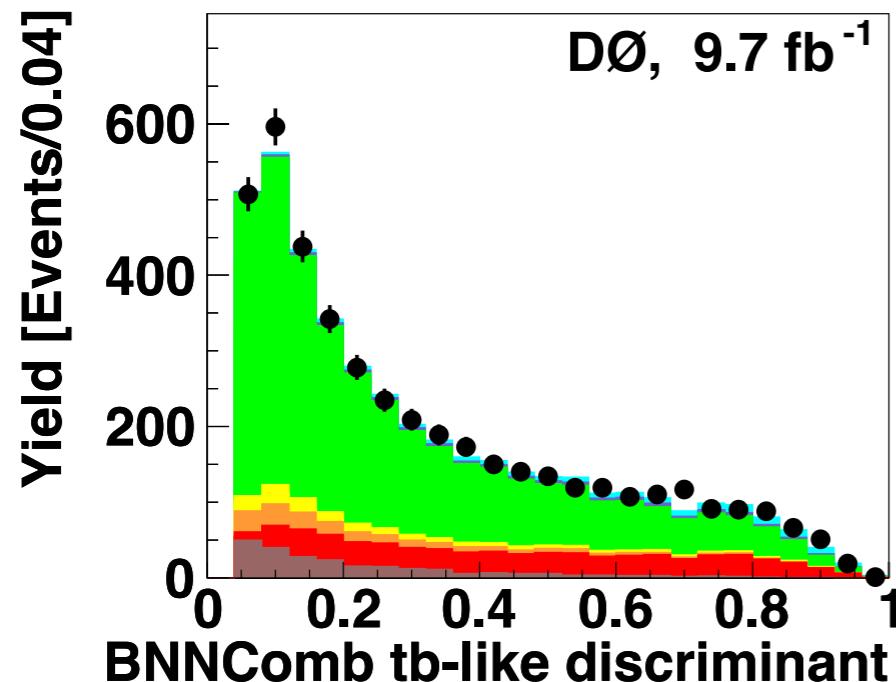
If $D_{tb} > D_{tqb}$:

- tb category
- Use D_{tb}
- Plot in the range $[0, 1]$



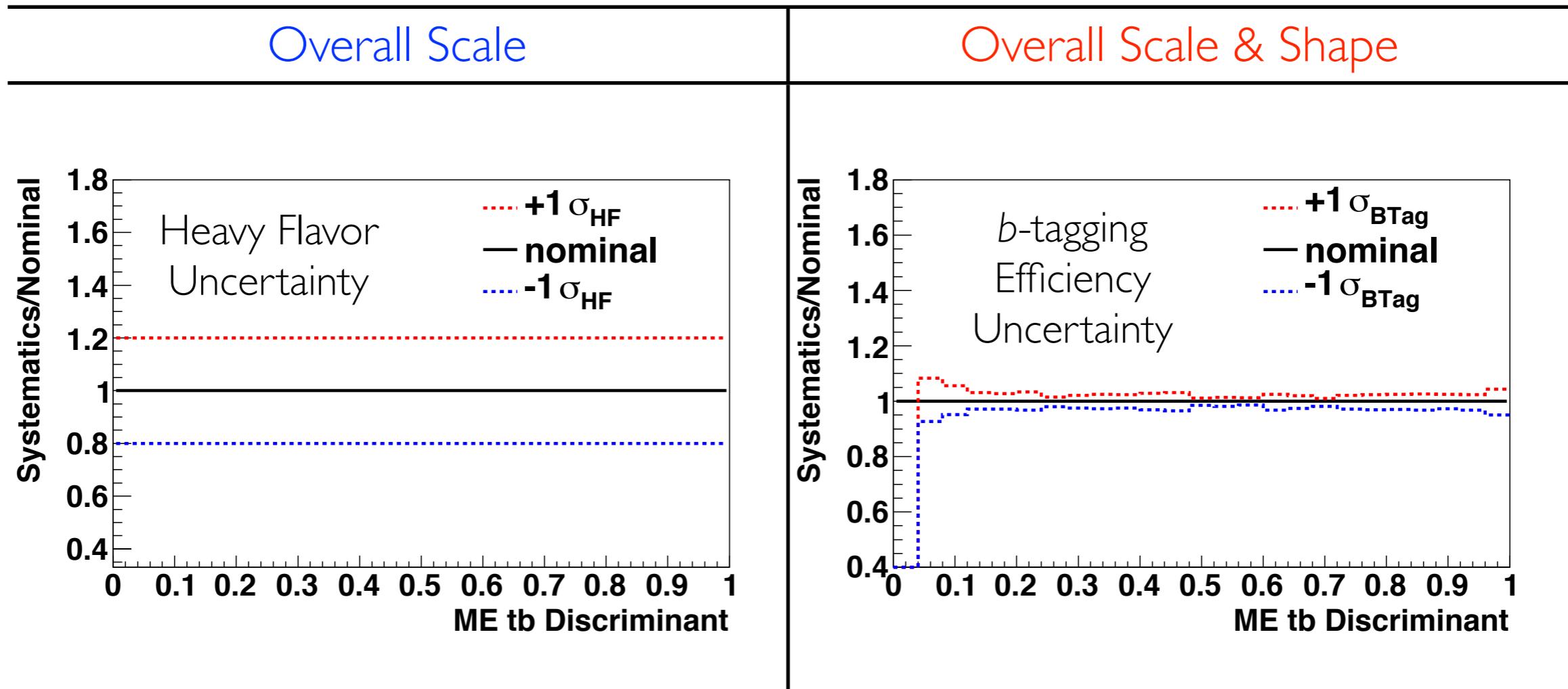
If $D_{tqb} > D_{tb}$:

- tqb category
- Use D_{tqb}
- Plot in the range $[1, 2]$



Systematic Uncertainties

- Assign to each background and each analysis channel
- Some affect only the **overall scale**, and others affect also the **discriminant outputs bin-by-bin (shape-changing)**



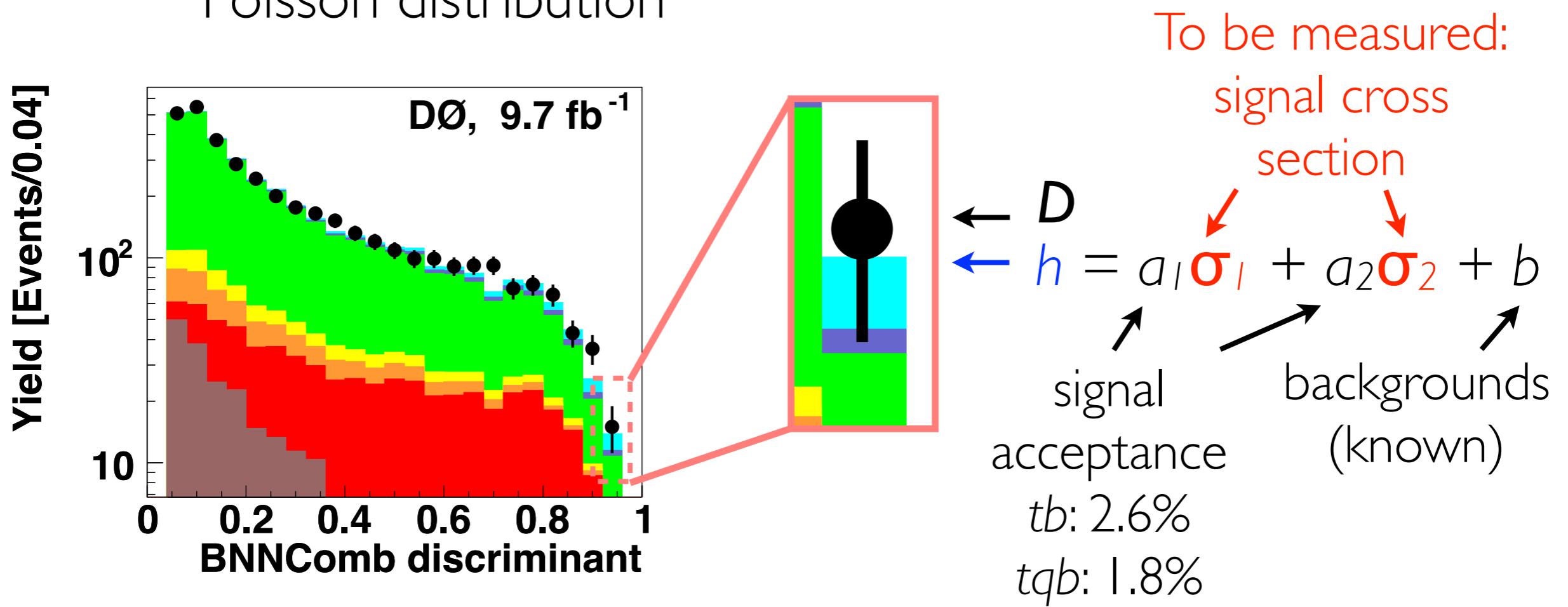
Systematic Uncertainties

- Assign to each background and each analysis channel
- Some affect only the **overall scale**, and others affect also **the discriminant outputs bin-by-bin (shape-changing)**
- Main uncertainties are listed here

Overall Scale	Overall Scale & Shape
Integrated luminosity	6.1%
Top pair cross section	9%
Diboson cross section	7%
Trigger efficiencies	(3-5)%
Jet fragmentation+higher order	(0.7-7.0)%
Initial- and final-state radiation	(0.8-10.9)%
Heavy-flavor correction	20%
Multijet normalization	(9.2-42.1)%

Cross Section Extraction

- Use the BNN combination discriminant in 25 bins
 - Use all bins (we don't cut on the discriminant)
- For each bin, the likelihood L to observe **D data events** with a **known mean h** is modeled by the Poisson distribution



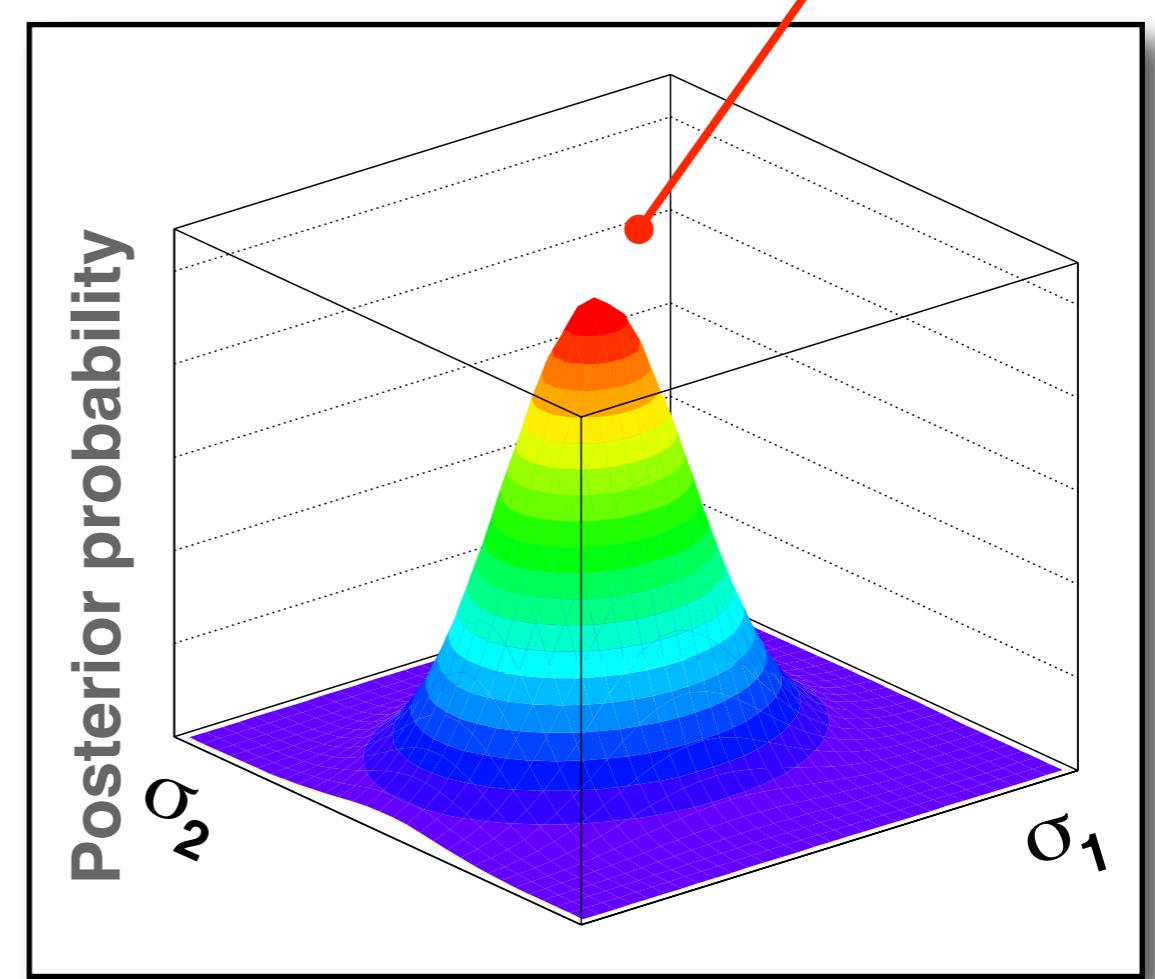
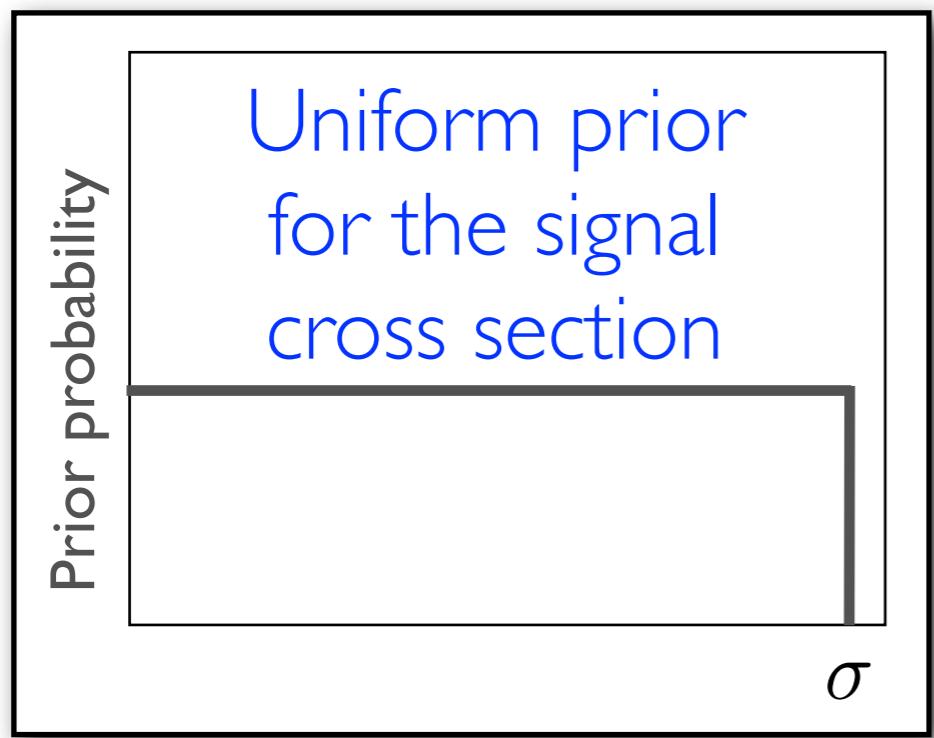
Bayesian Approach

Poisson likelihood

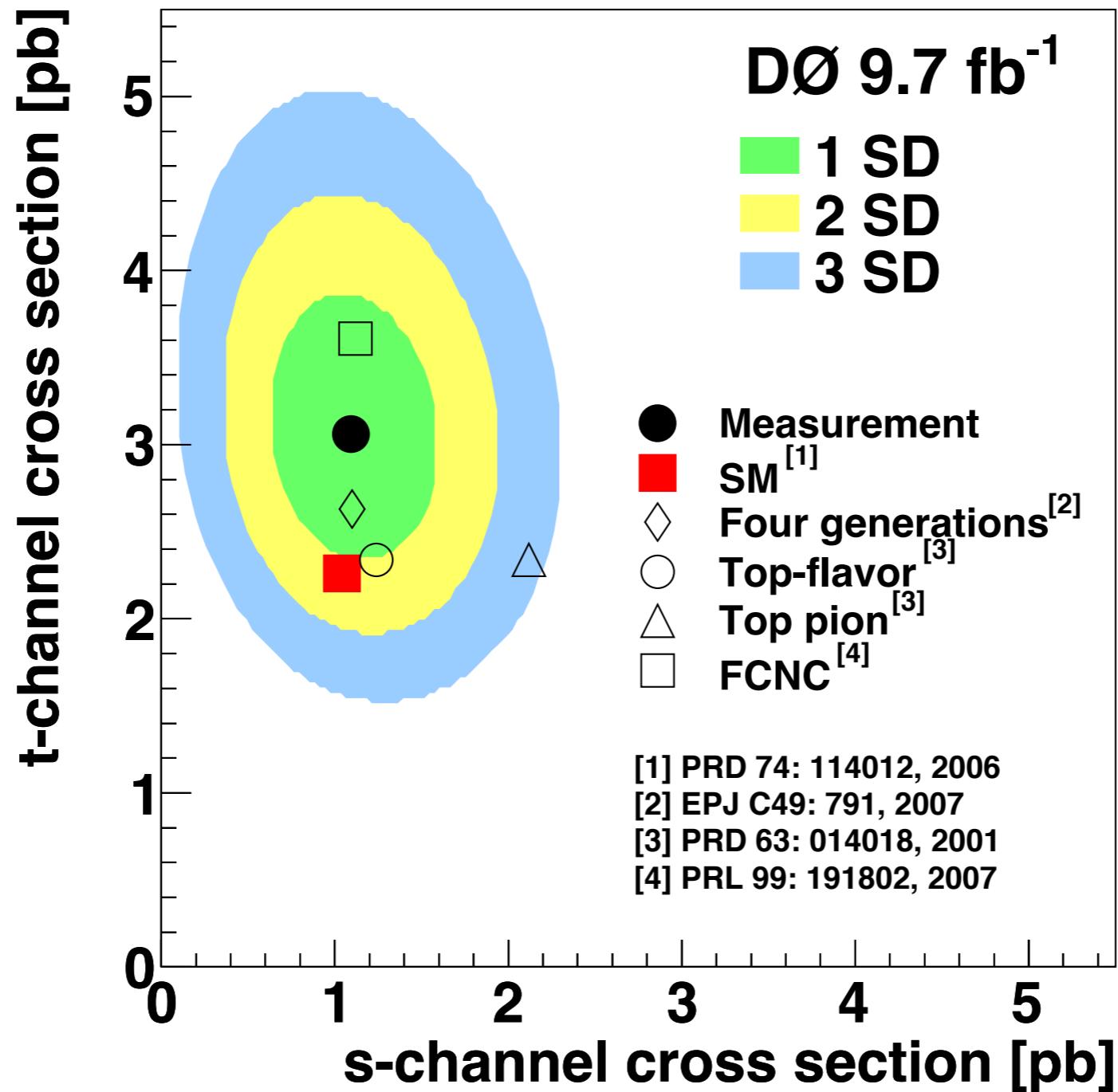
$$\int L(\mathbf{D}|\sigma_1, \sigma_2, \mathbf{a}_1, \mathbf{a}_2, \mathbf{b}) \pi(\sigma_1, \sigma_2) \pi(\mathbf{a}_1, \mathbf{a}_2, \mathbf{b}) d\mathbf{a}_1 d\mathbf{a}_2 db \propto p(\sigma_1, \sigma_2 | D)$$

Our state of knowledge, a, b with systematic uncertainties

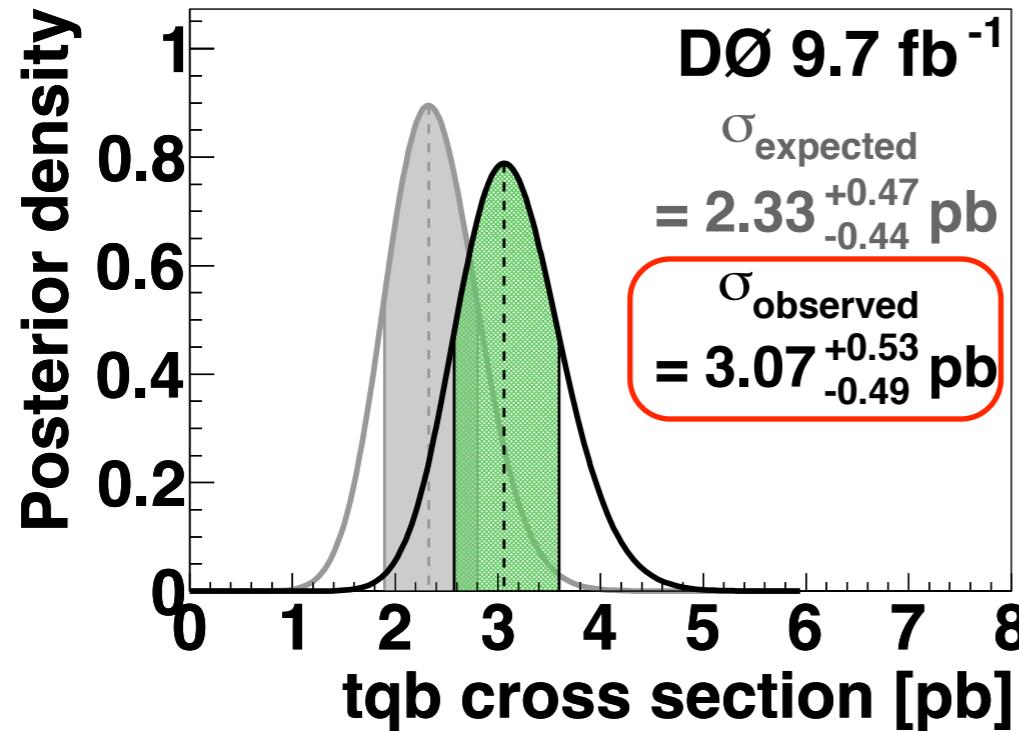
All systematics and their correlations taken into account



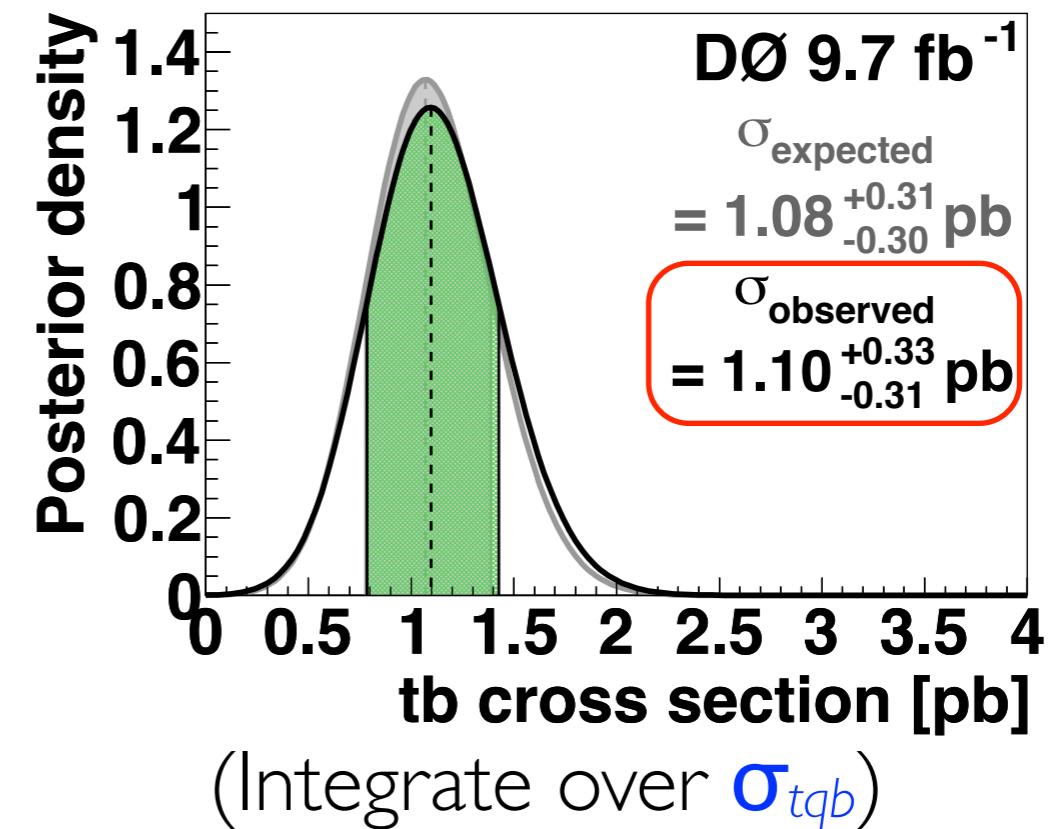
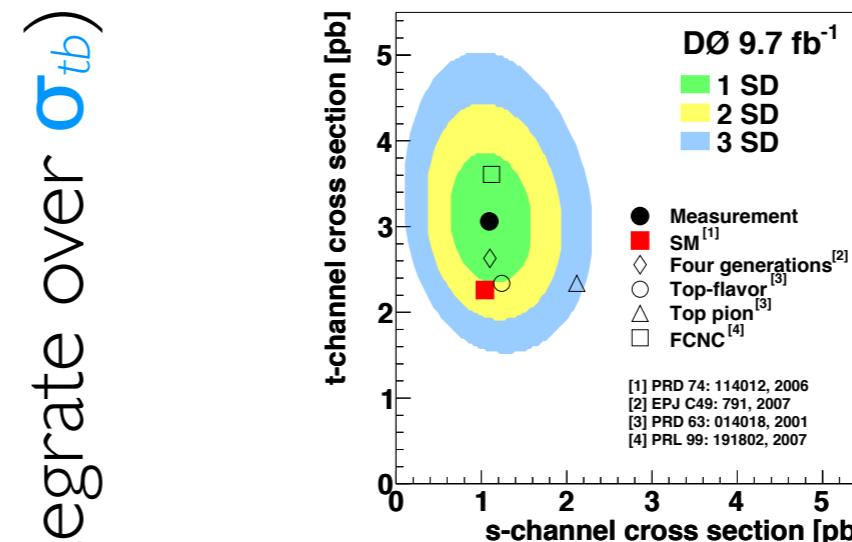
Two-dimensional Posterior



Measured Cross Section

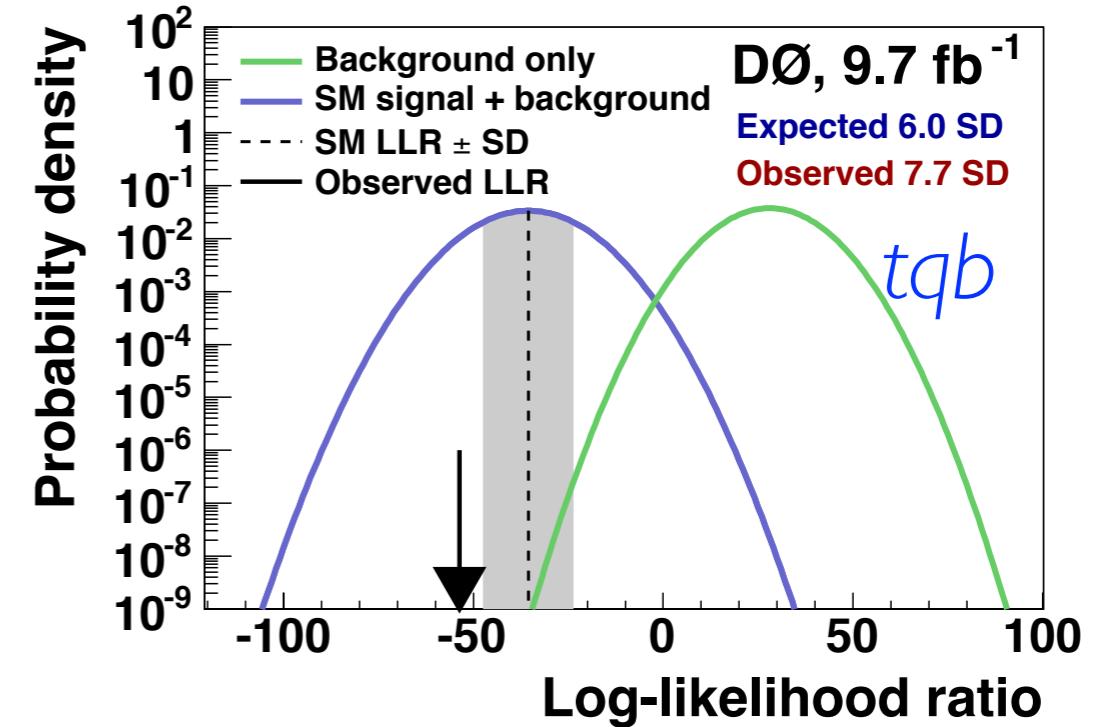
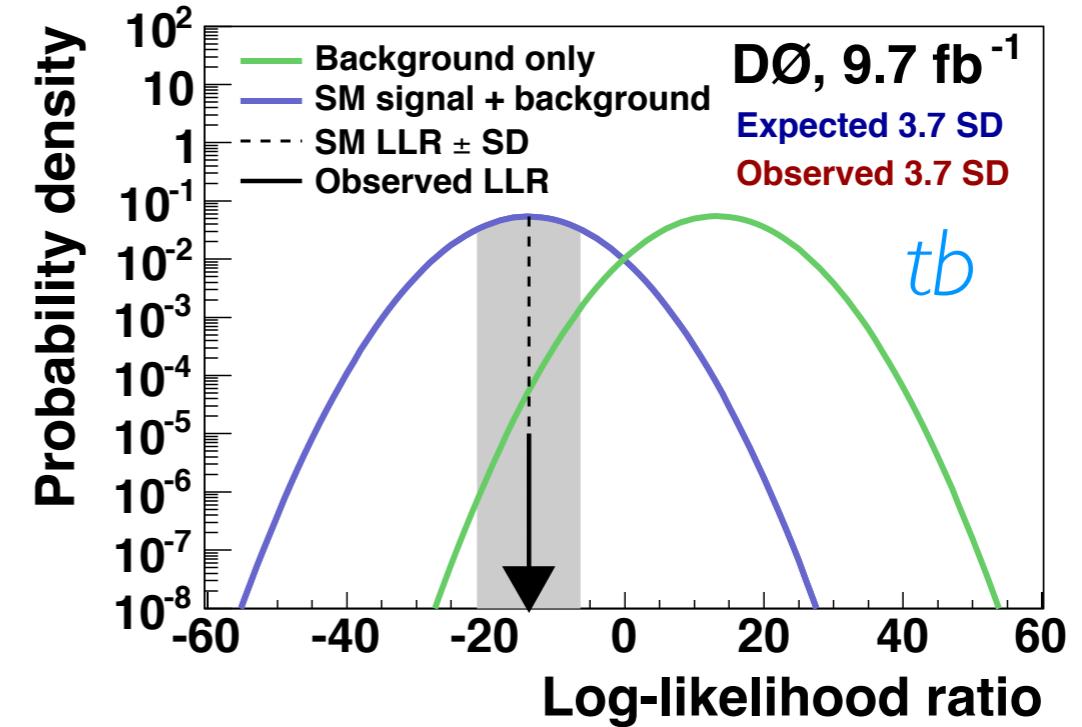


No assumption
on SM σ_{tb}/σ_{tqb} !

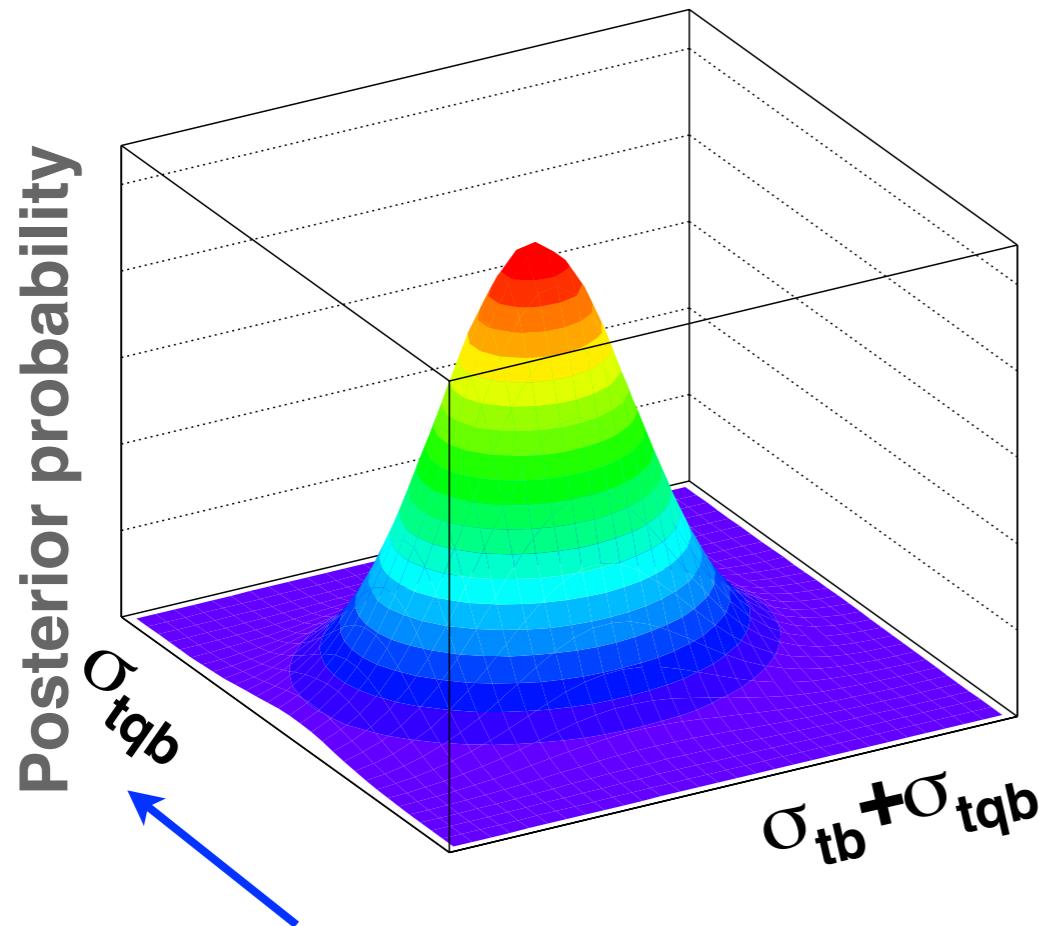


Significance

- Asymptotic approximation of the log-likelihood ratio
 - tests how likely the data is to fluctuate to the measured σ value, in the absence of the signals
- Expected p-values:
 - $t b$: 1.0×10^{-4} (3.7 SD)
 - $t q b$: 9.9×10^{-10} (6.0 SD)
- Observed p-values:
 - $t b$: 1.0×10^{-4} (3.7 SD)
 - $t q b$: 6.1×10^{-15} (7.7 SD)

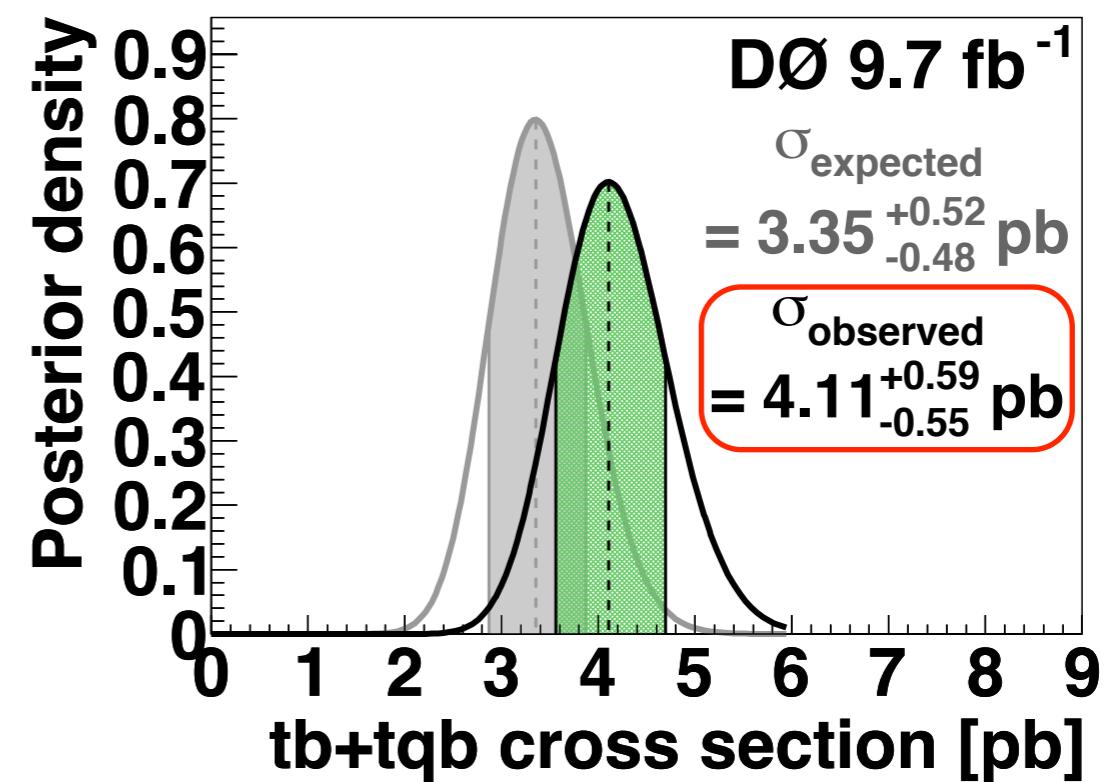


Measured σ_{tb+tqb}



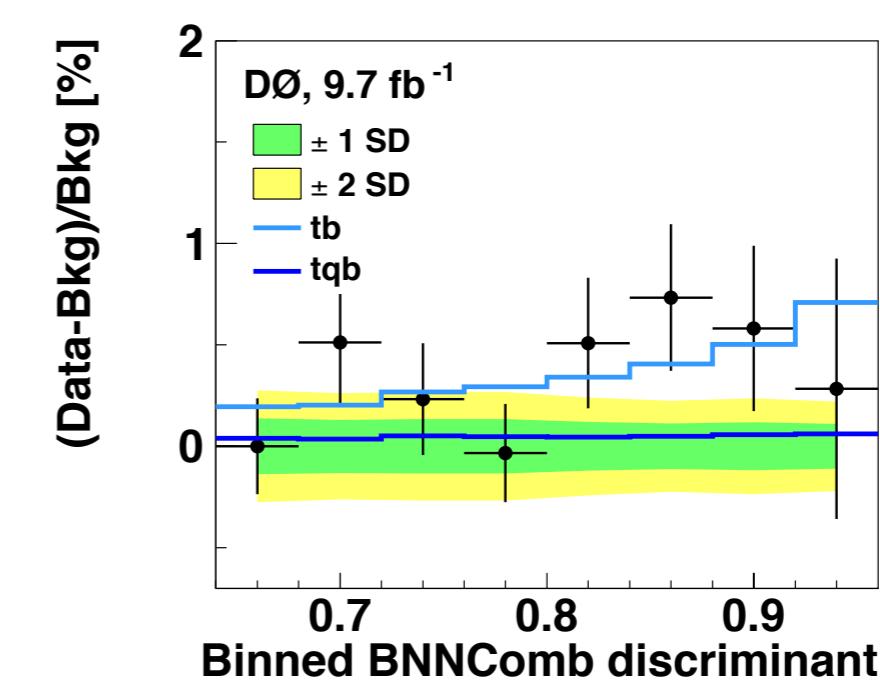
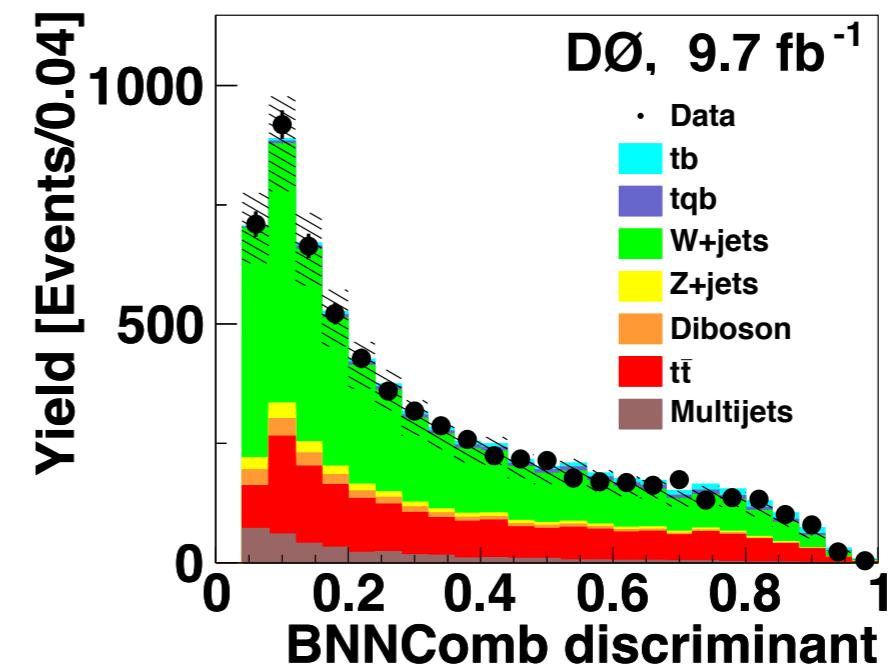
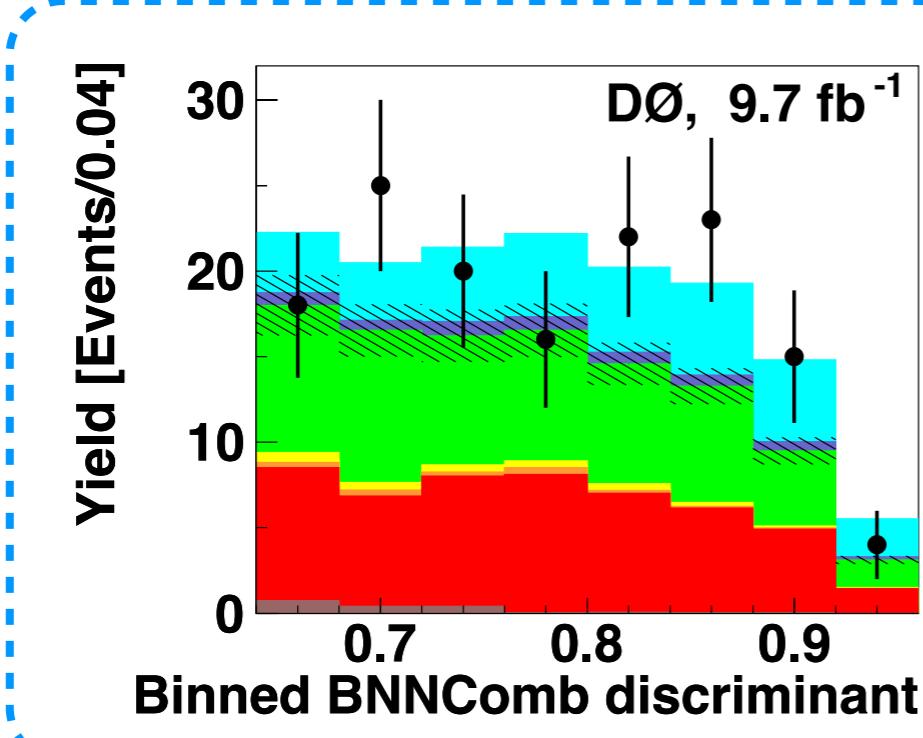
Integrate over σ_{tqb} and obtain a 1D posterior p.d.f. of σ_{tb+tqb}

- Measure σ_{tb+tqb} without assuming the SM σ_{tb}/σ_{tqb}
- Use 2D posterior p.d.f.



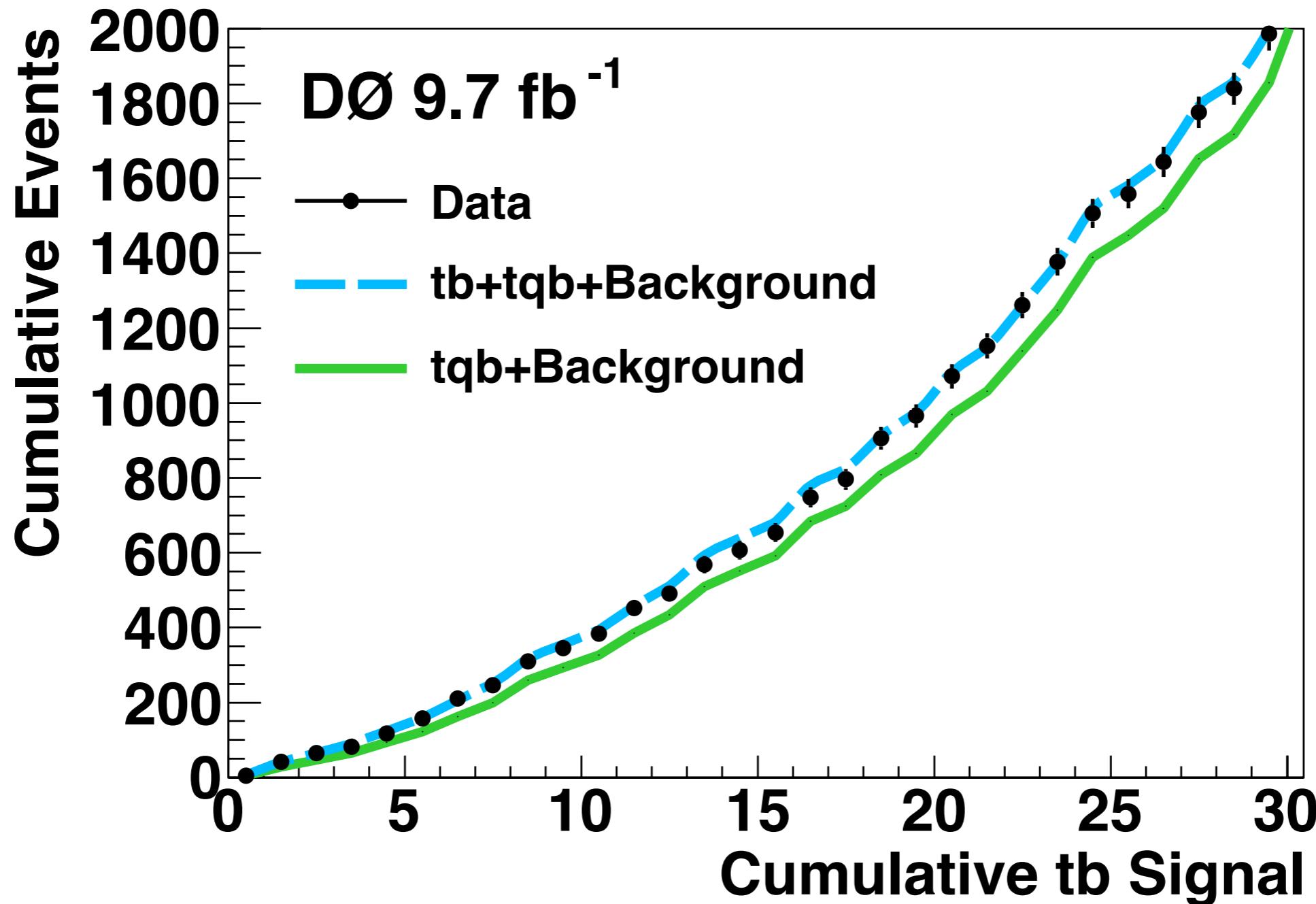
tb or Not tb?

- BNNComb discriminant with the post-fit uncertainty
- Examine the most sensitive bins (largest S/B)
- Data favors the “truth and beauty”!



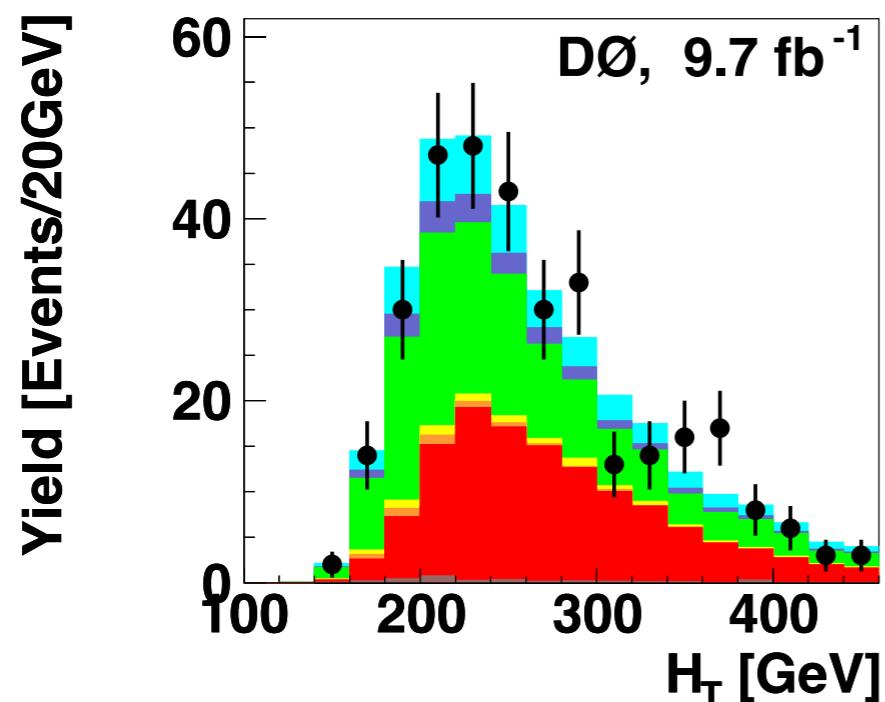
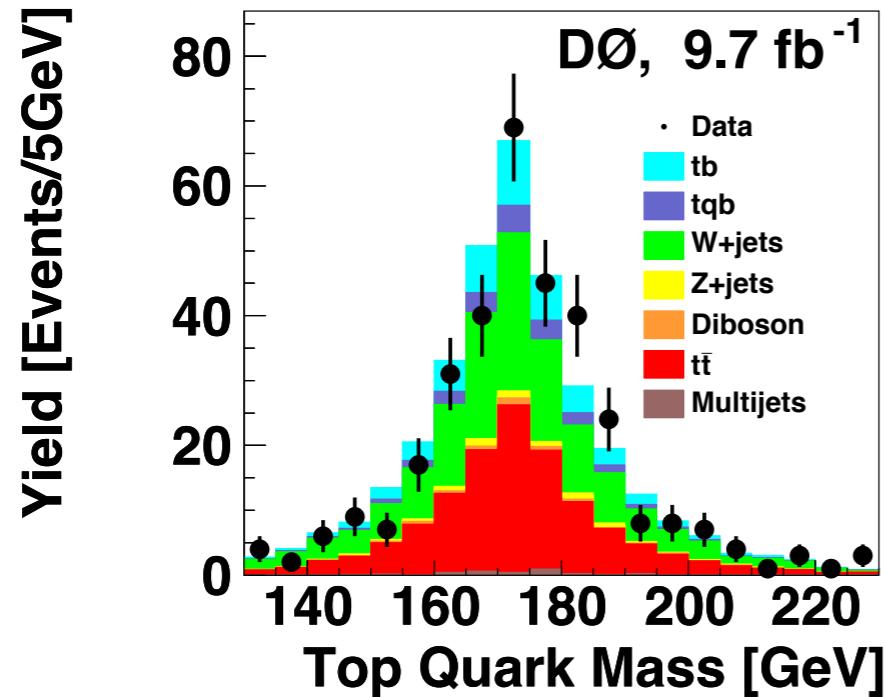
Cumulative tb-Signal Plot

Integrating from the high significance bins backward

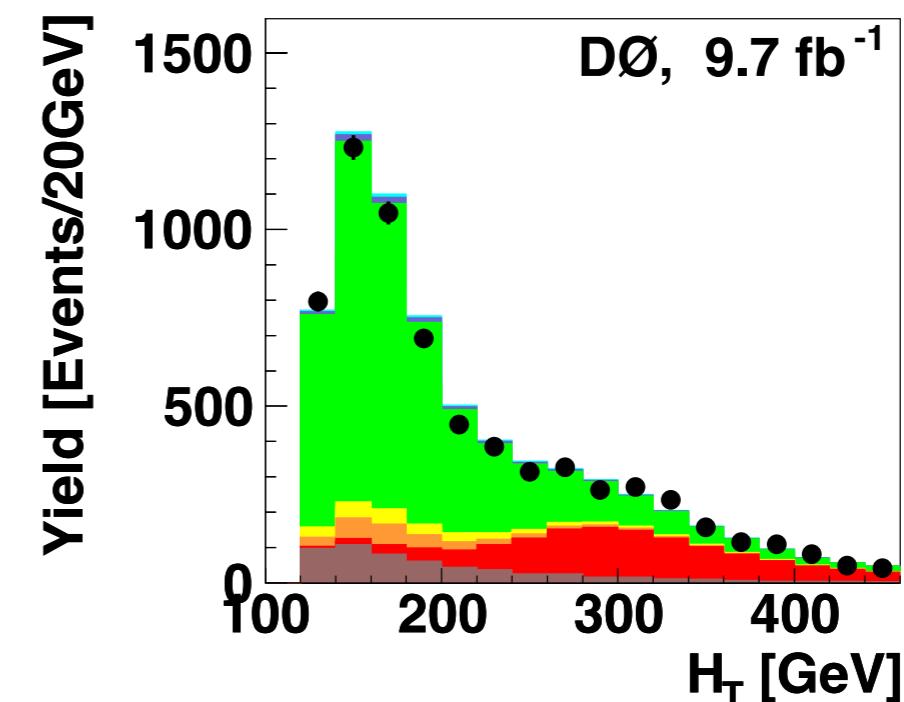
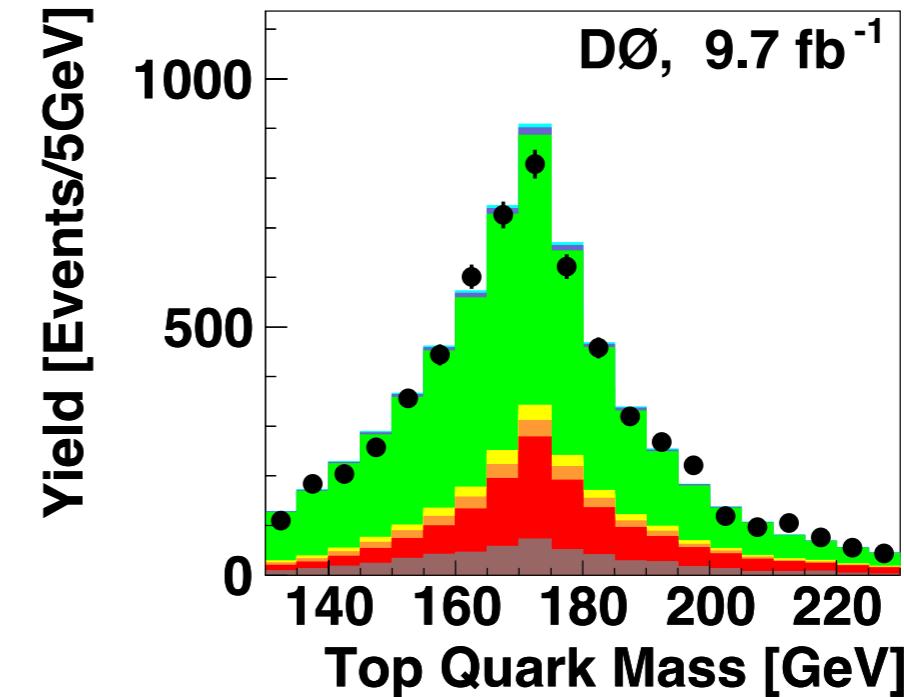


Event Characteristics

tb Category: $D_{tb} > 0.8$

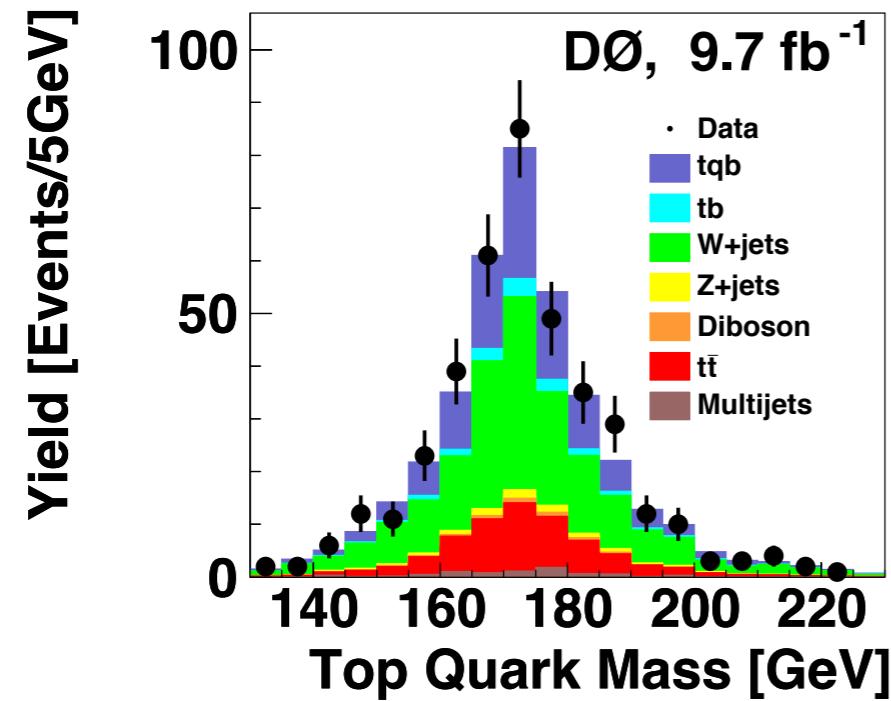


tb & *tqb* Depleted Region

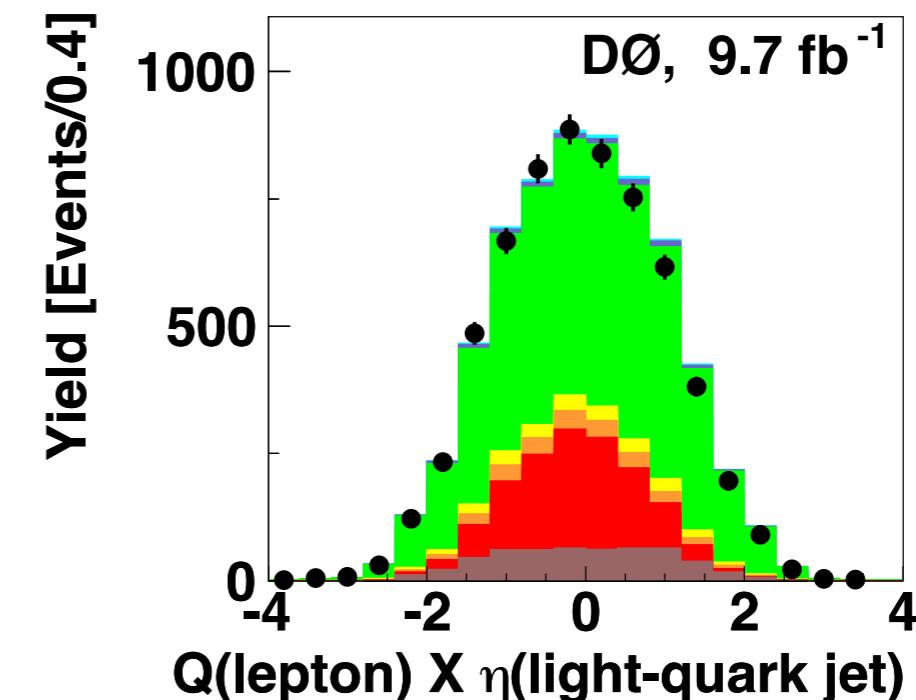
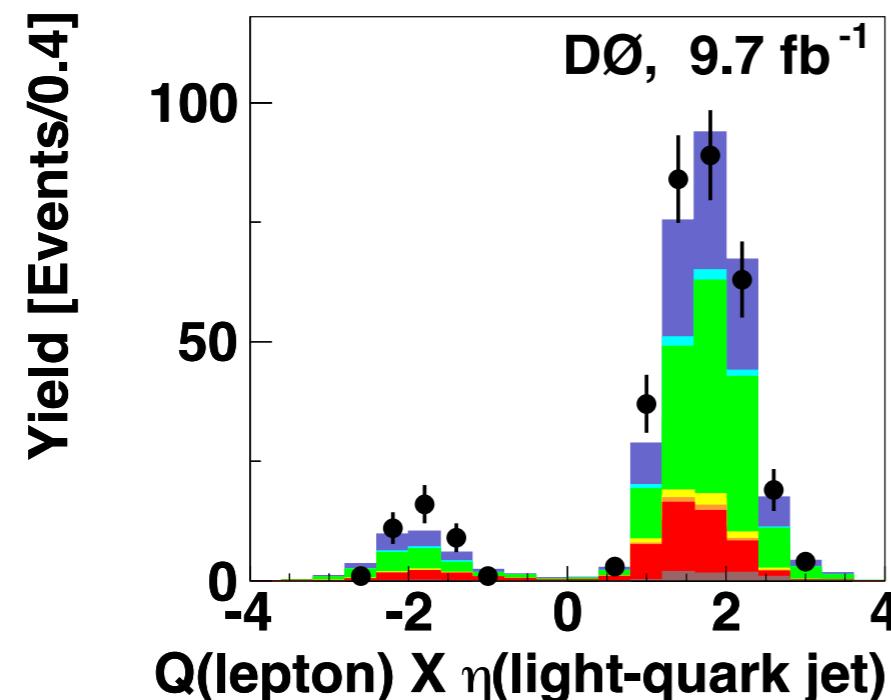
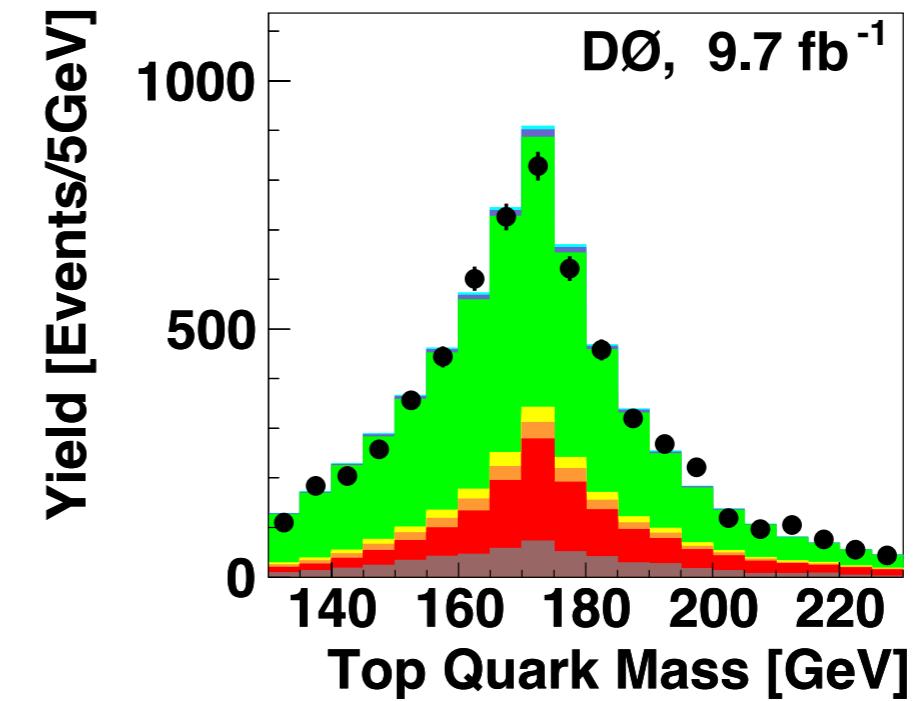


Event Characteristics

tqb Category: $D_{tqb} > 0.8$



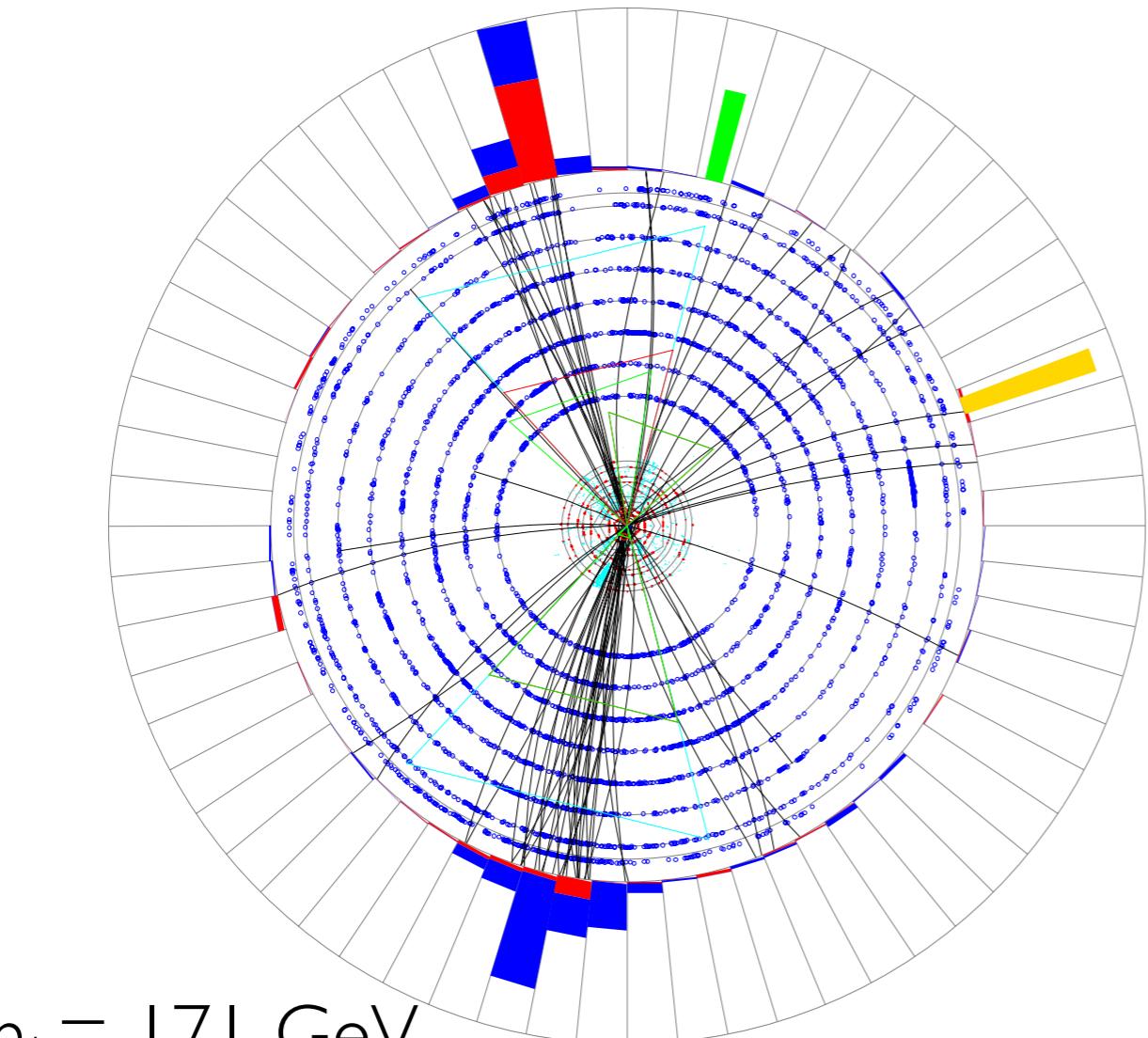
tb & tqb Depleted Region



A $t\bar{b}$ Candidate

Run 252918 Evt 51093921 Sat Jun 13 23:07:10 2009

ET scale: 54 GeV



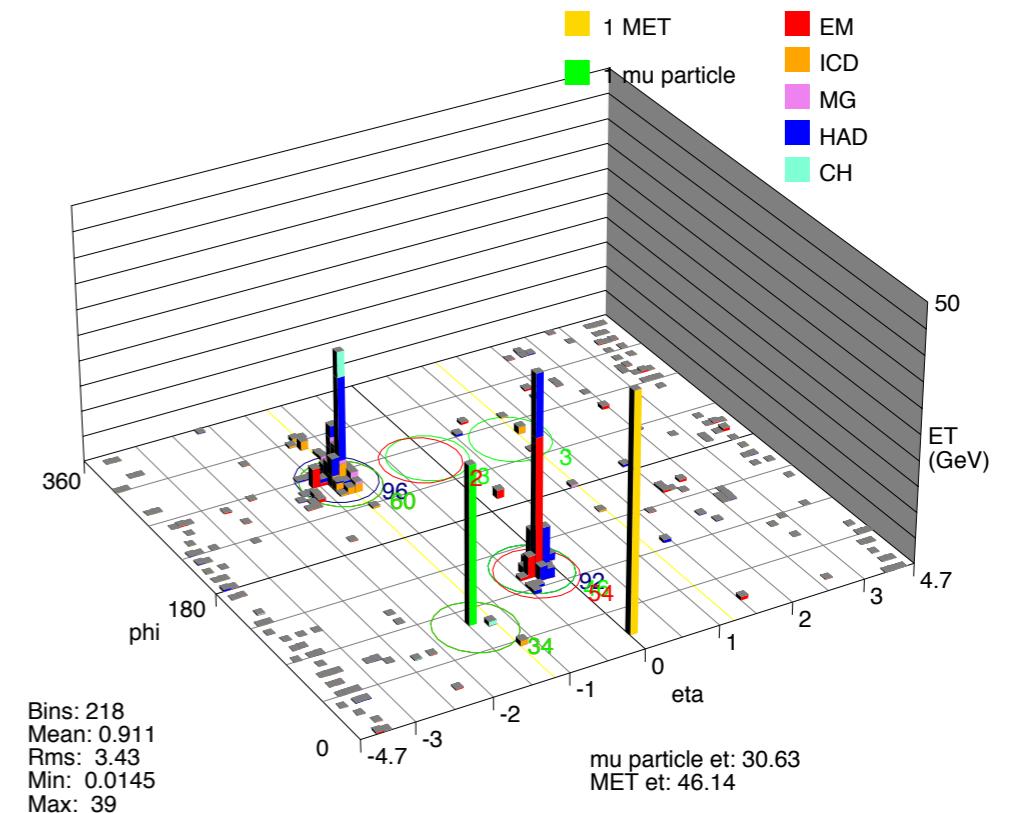
$m_t = 171 \text{ GeV}$

Jet1 b-tag: 0.95

Jet2 b-tag: 0.84

Run 252918
Event 51093921
Sat. June 13 23:07:10 2009

Run 252918 Evt 51093921 Sat Jun 13 23:07:10 2009



Single Top Today

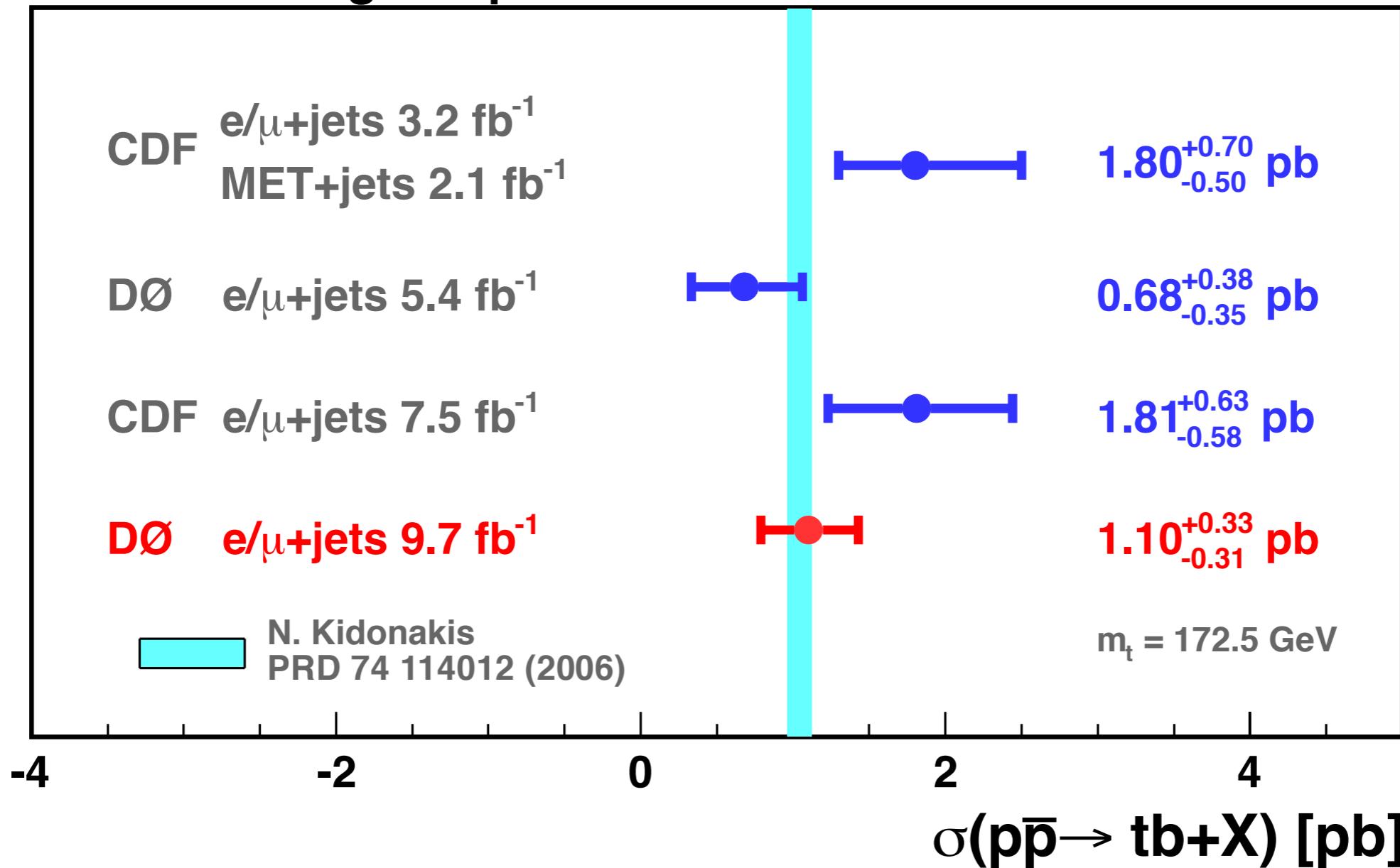
σ (pb) ~NNLO	tb	tqb	tW
Tevatron Prediction (1.96 TeV)	1.04	2.26	0.3
CDF (7.5 fb ⁻¹)	1.81 ± 0.6	1.49 ± 0.45	-
DØ (9.7 fb ⁻¹)	<input type="checkbox"/> 1.10±0.33	<input checked="" type="checkbox"/> 3.07±0.53	-
LHC Prediction (7 TeV)	4.6	64.6	15.7
ATLAS (0.7-2.1 fb ⁻¹)	< 20.5 (95% C.L.)	<input checked="" type="checkbox"/> 83±20	<input type="checkbox"/> 17±6
CMS (1.2-4.9 fb ⁻¹)	-	<input checked="" type="checkbox"/> 67±6	<input type="checkbox"/> 16±5

Evidence (3 SD)

Observation (5 SD)

σ_{tb} Measurement History

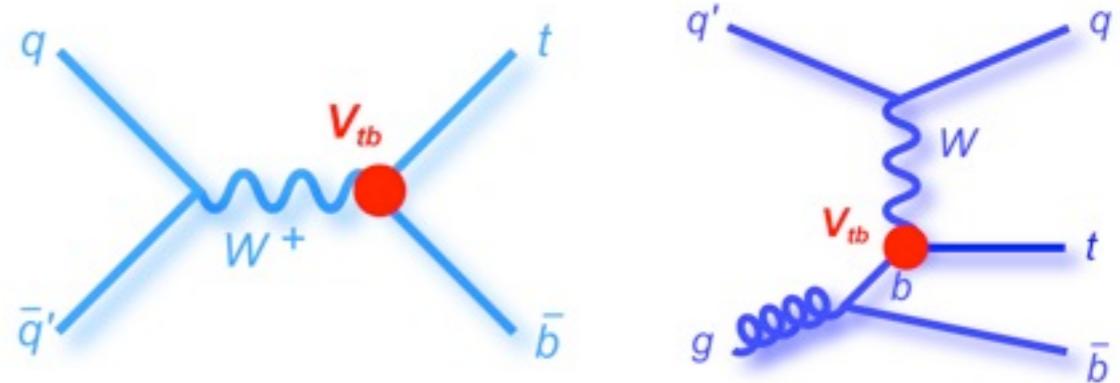
s-channel Single Top Quark Cross Section



Each single method in the DØ 9.7 fb⁻¹ analysis measures σ_{tb} with > 3 SD

CKM Matrix Element $|V_{tb}|$

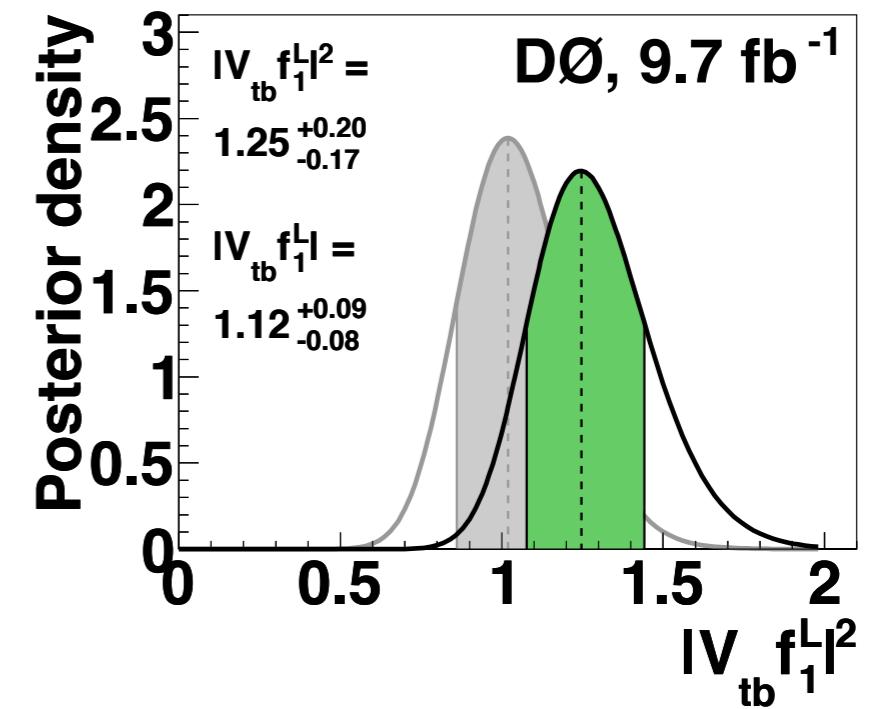
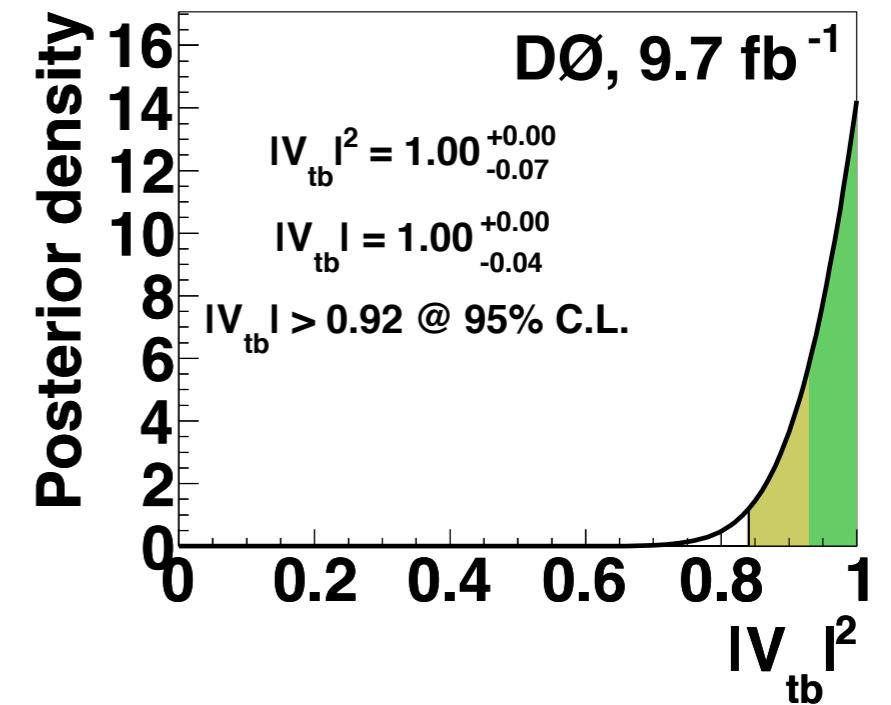
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



- σ_{tqb} proportional to $|V_{tb}|^2$
- Lagrangian: $\mathcal{L} = -\frac{g}{\sqrt{2}} V_{tb} \bar{b} \gamma^\mu (f_1^L P_L) t W_\mu^-$ SM: $f_1^L = 1$
- Assume:
 - SM top decay: $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$
 - Pure V-A interaction
 - CP conservation
- DO NOT assume
 - 3 generations
 - unitarity of the CKM matrix; allow $|V_{tb} f_1^L|^2 > 1$
 - σ_{tb}/σ_{tqb} (NEW)

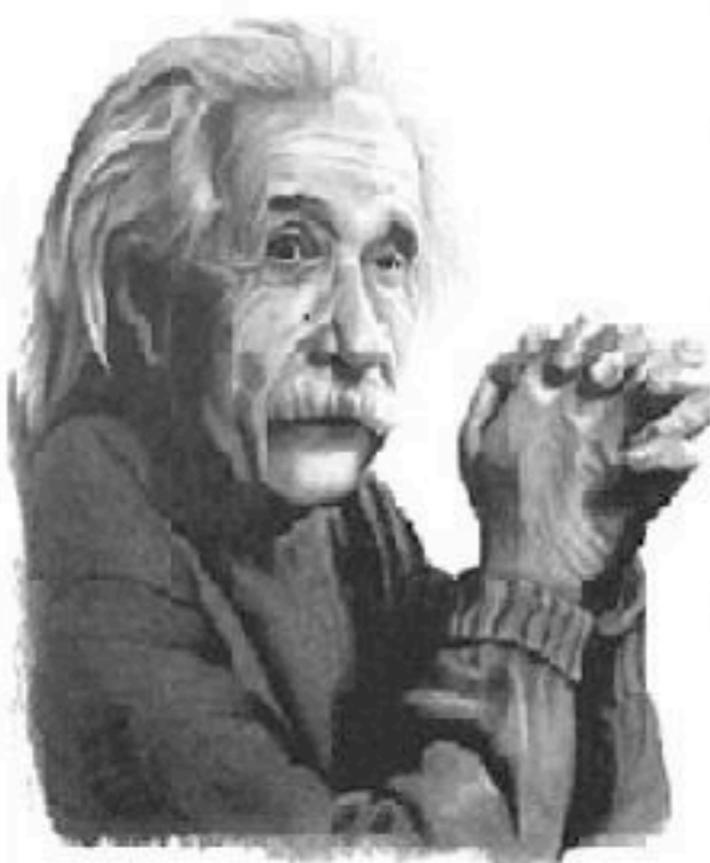
CKM Matrix Element $|V_{tb}|$

- Assume $0 \leq |V_{tb}|^2 \leq 1$
 - $|V_{tb}| > 0.92 @ 95\% \text{ C.L.}$
- Allow $|V_{tb} f_1^L|^2 > 1$
 - $|V_{tb} f_1^L| = 1.12^{+0.09}_{-0.08}$
- Additional systematic uncertainties
 - theoretical uncertainty on single top cross sections
- Complementary to $R_{Wb/Wq}$ measurement in top decays
PRD 85, 091104 (2012)



Conclusion

- First evidence of s-channel single top quark production
 - $\sigma_{tb} = 1.10 \pm 0.33 \text{ pb}$
 - simultaneously measure σ_{tb} and σ_{tqb} , without assuming the SM prediction for either
- Also measure σ_{tb+tqb} and $|V_{tb}|$ without assuming the SM ratio of σ_{tb}/σ_{tqb}
 - $|V_{tb}| > 0.92 @ 95\% \text{ C.L.}$
- The results are consistent with the SM predictions
- A legacy measurement at the Tevatron
 - looking forward to combining with CDF



quotespedia.info

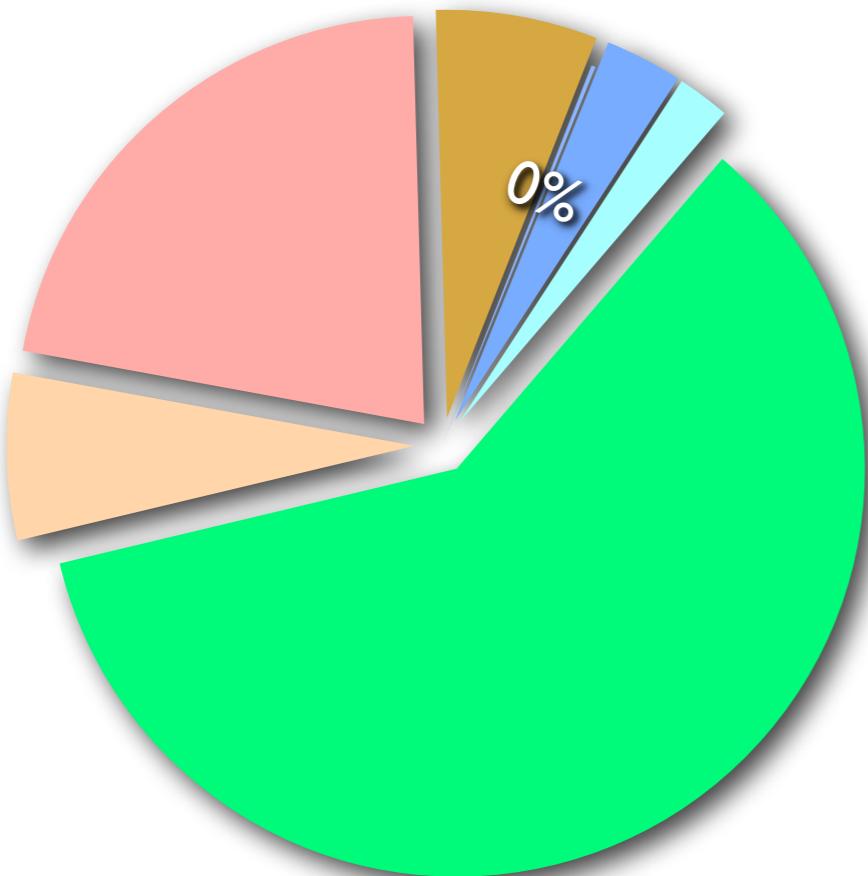
The pursuit of truth and
beauty is a sphere of
activity in which we are
permitted to remain children
all our lives.

Albert Einstein

Thank you for your attention!

Backup Slides

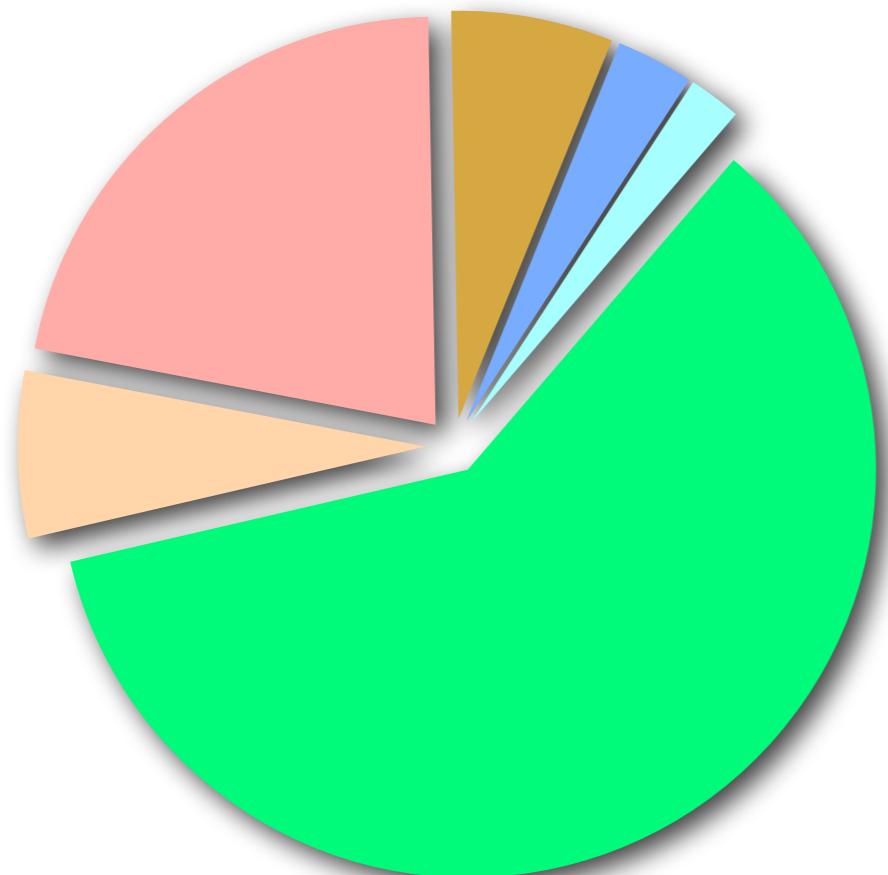
tW Contribution at DØ



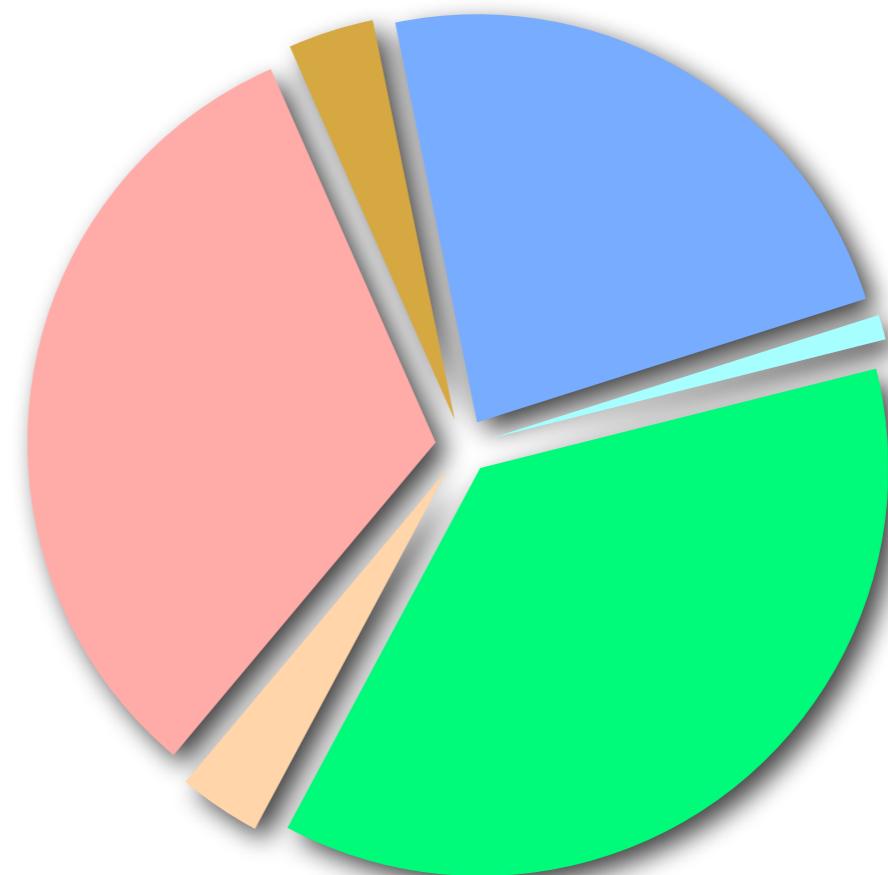
e, μ 2, 3-jets 1, 2 b -tags combined	
s -channel	257
t -channel	378
tW	20
$W+\text{jets}$	7394
diboson, $Z+\text{jets}$	815
top pair	2672
multijet	789
Total background	11669
Data	12103

Background Contribution

DØ



CMS
(arXiv:1209.4533v1)



s-channel t-channel W+jets Z+jet, dibosons tt+tW Multijets

Additional Cuts

- $H_T > 120/140/160 \text{ GeV}$ (2/3/4 jet)
- $\text{MET} > 25 \text{ GeV}$ (3 and 4 jet)
- $\Delta\varphi(\text{MET}, \text{Jet1}) < 1.5 + 0.0469\text{MET}$
- Electron channel
 - $\Delta\varphi(\text{MET}, \text{Lep}) > 2.0 - 0.05\text{MET}$
 - $\Delta\varphi(\text{MET}, \text{Lep}) > 1.5 - 0.03\text{MET}$
 - $\Delta\varphi(\text{MET}, \text{Lep}) < 2.0 + 0.0476\text{MET}$
- Muon channel
 - $\Delta\varphi(\text{MET}, \text{Lep}) > 1.4 - 0.0141\text{MET}$
 - $\Delta\varphi(\text{MET}, \text{Lep}) < 2.5 + 0.0214\text{MET}$
 - $-ab/(\pi-a) + b \Delta\varphi(\text{MET}, \text{Lep})/(\pi-a) < |\mu_{trkcursig}|$
 $(a, b) = (2.9, 10)$ (modified)
- Trapezoid cut (new)

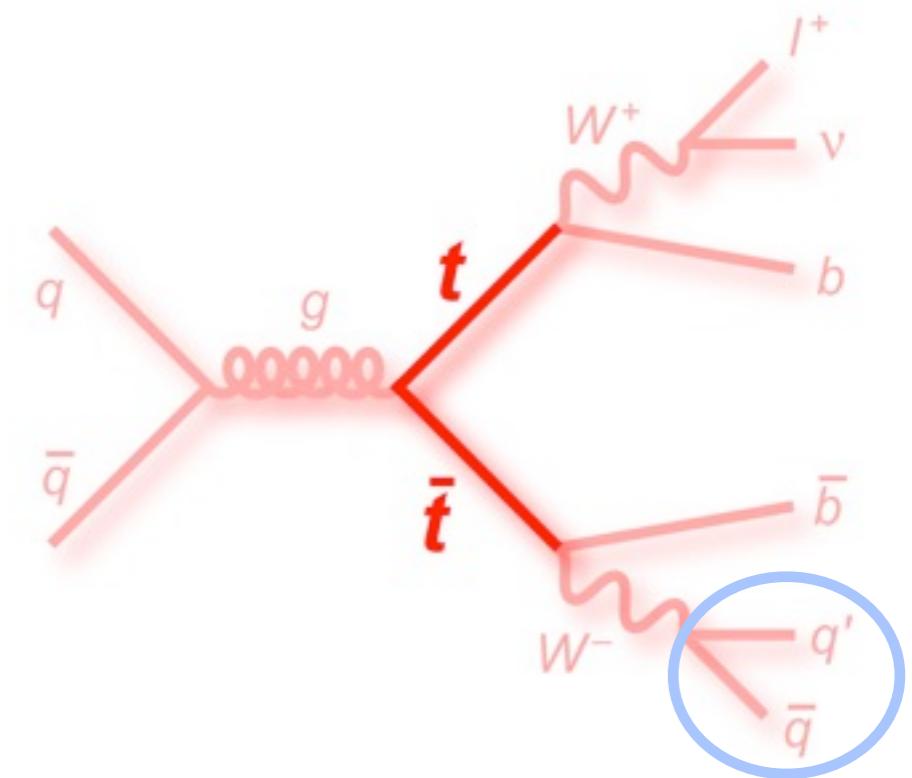
Matrix Element Processes

Two Jets		Three Jets	
Name	Process	Name	Process
$\textcolor{cyan}{tb}$	$u\bar{d} \rightarrow t\bar{b}$	$\textcolor{cyan}{tbg}$	$u\bar{d} \rightarrow t\bar{b}g$
tq	$ub \rightarrow td$ $\bar{d}b \rightarrow t\bar{u}$	$\textcolor{blue}{tqb}$	$ug \rightarrow t\bar{d}\bar{b}$ $\bar{d}g \rightarrow t\bar{u}\bar{b}$
		$\textcolor{blue}{tqg}$	$ub \rightarrow tdg$ $\bar{d}b \rightarrow t\bar{u}g$
Wbb	$u\bar{d} \rightarrow Wb\bar{b}$	$Wbbg$	$u\bar{d} \rightarrow Wb\bar{b}g$
Wcg	$sg \rightarrow Wcg$	$Wugg$	$\bar{u}g \rightarrow W\bar{u}gg$
Wgg	$u\bar{d} \rightarrow Wgg$		
WW	$u\bar{u} \rightarrow WW$		
WZ	$u\bar{d} \rightarrow WZ$		
ggg	$gg \rightarrow ggg$		
$t\bar{t}$	$u\bar{u} \rightarrow t\bar{t}$	$t\bar{t}$	$u\bar{u} \rightarrow t\bar{t}$

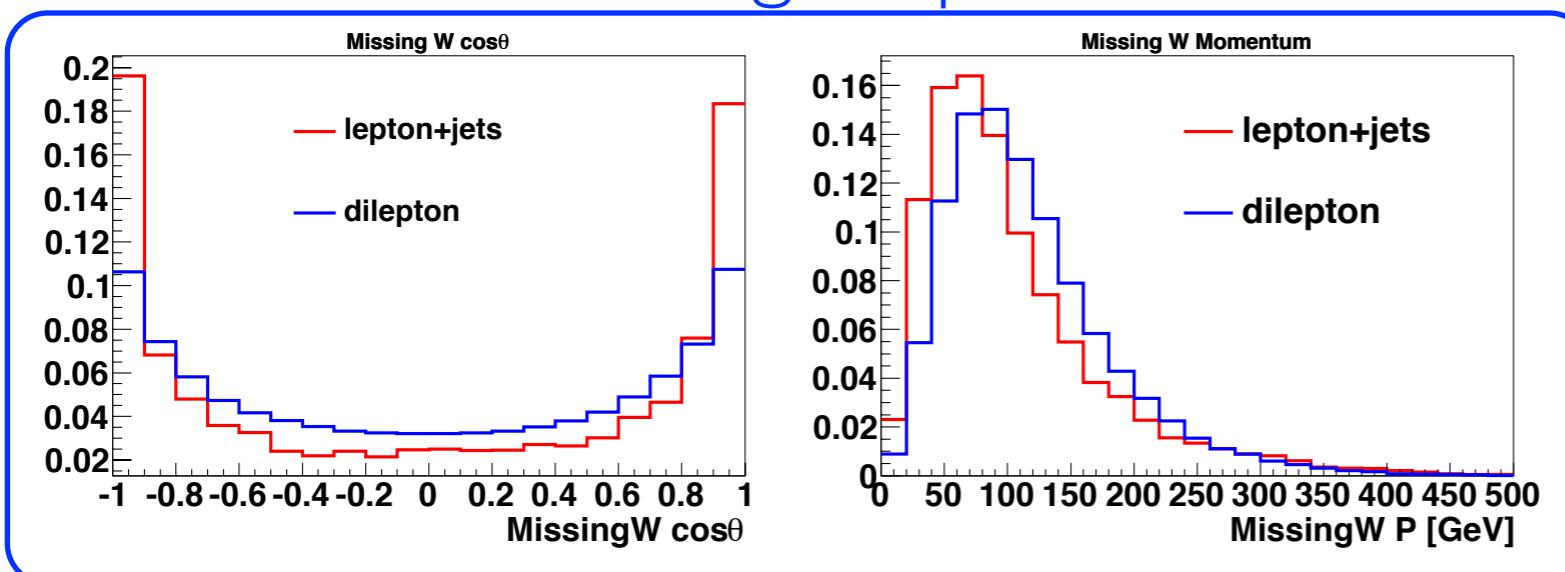
- the more background diagrams, the better discrimination

Top Pair Modeling

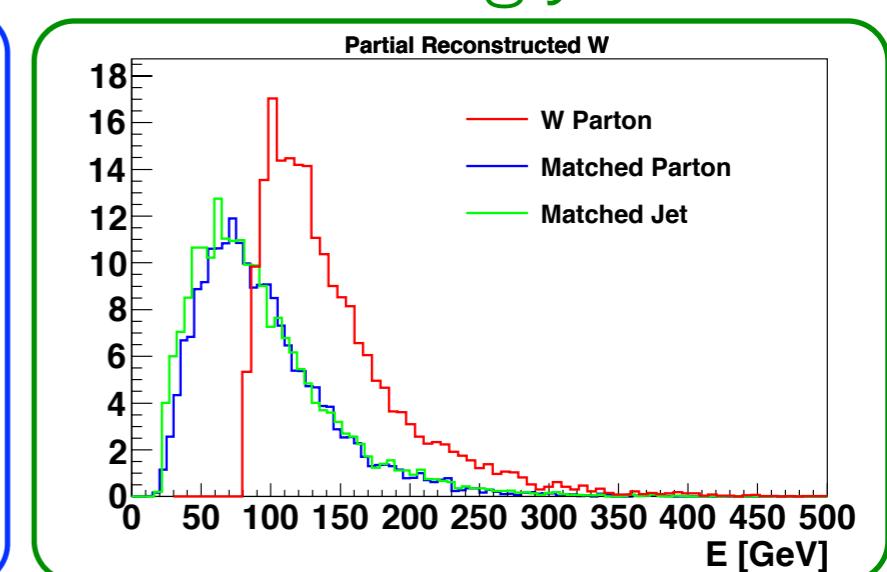
- Top pair $\rightarrow l\nu b\bar{q}q'b$ (4 jets)
- Top pair yields in 2jet & 3jet channels are comparable to single top
- Light-jets are 1.6 times more likely to be lost than b -jets
- Use simulation to derive a prior of missing jet (3jet) or missing W (2jet)



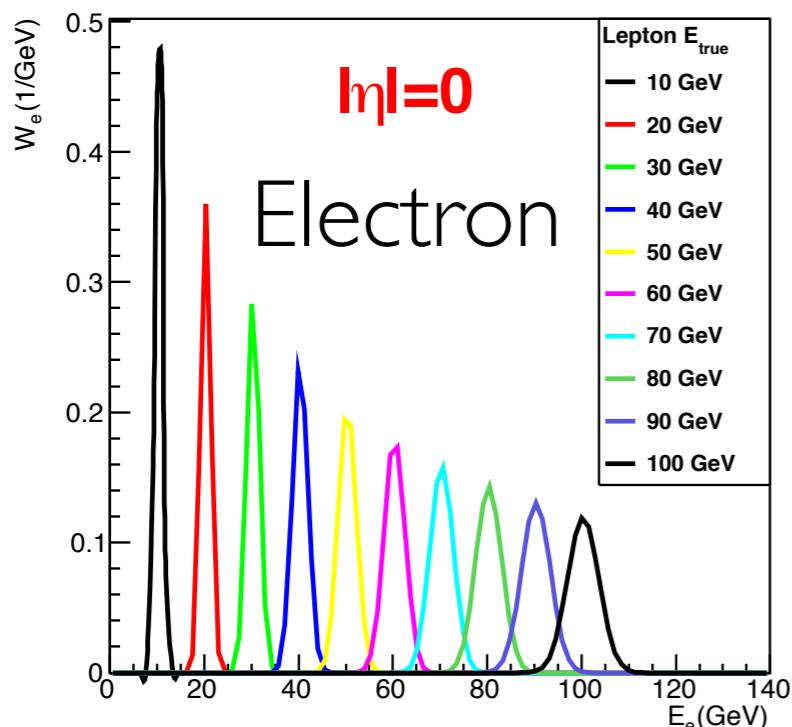
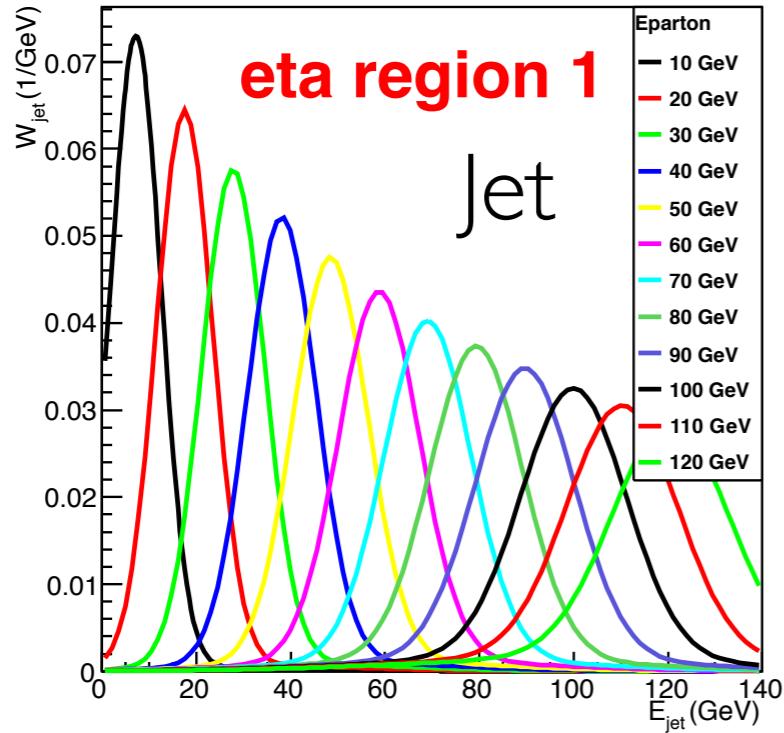
Missing W prior



Missing Jet



Transfer Functions: $W(\vec{x}, \vec{y})$



- Model the detector resolution effects
- For all final state objects: electrons, muons, jets, and jets mis-reconstructed as electrons
- Gaussian functions of difference between:
 - reconstructed and true energy (electrons, jets, fake electrons)
 - reconstructed and true transverse momentum (muons)
- Parameters determined from the simulated samples

Dimensionality of Phase Space

	D.O.F.	$n=4$ (2jets)	$n=5$ (3jets)
2 initial and n final state objects	$(2+n) \times 4$	24	28
Energy and momentum conservation	-4	-4	-4
All masses are known	$-(2+n)$	-6	-7
The initial partons are in z -axis	-2×2	-4	-4
The directions of the final objects are well measured, except neutrinos	$-2 \times (n-1)$	-6	-8
Remaining dimensions	n	4	5
Final integration for signals		$S_W, S_t, P_q, P_{q,z}^{\text{tot}}$	$S_W, S_t, P_q, P_{q',z}^{\text{tot}}$

Discriminant

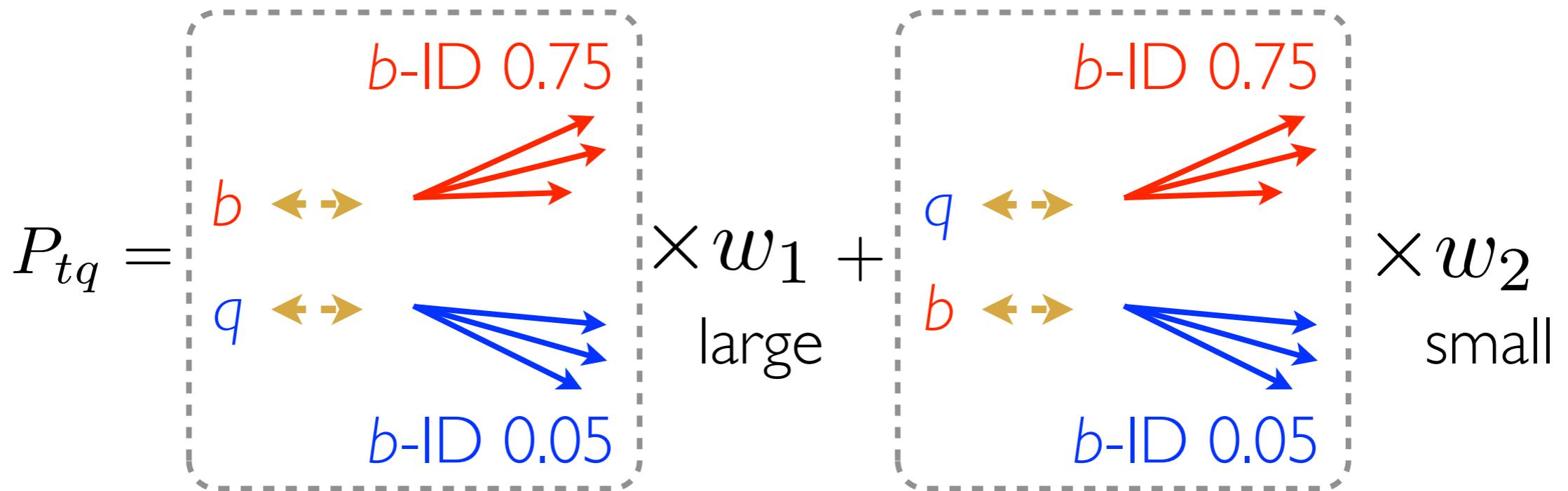
- b -ID output information included

$$P_{tq} = \begin{array}{c} b \\ q \end{array} \leftrightarrow \begin{array}{c} b\text{-ID } 0.75 \\ b\text{-ID } 0.05 \end{array} \times w_1 + \begin{array}{c} q \\ b \end{array} \leftrightarrow \begin{array}{c} b\text{-ID } 0.75 \\ b\text{-ID } 0.05 \end{array} \times w_2$$

The diagram illustrates a discriminant function P_{tq} as a weighted sum of two components. Each component consists of a pair of inputs (b and q) and their corresponding output vectors (red and blue arrows) labeled with b -ID values (0.75 and 0.05). The first component is labeled 'large' and the second is labeled 'small'. The weights w_1 and w_2 are indicated by the labels 'large' and 'small' respectively.

Discriminant

- b -ID output information included



- Discriminant: Likelihood ratio

$$D(x) = \frac{P_{sig}(x)}{P_{sig}(x) + P_{bkgd}(x)}$$

Bayesian Approach

- Bayes' theorem

$$p(\sigma|D) = \frac{p(D|\sigma)p(\sigma)}{p(D)}$$

- Posterior p.d.f.

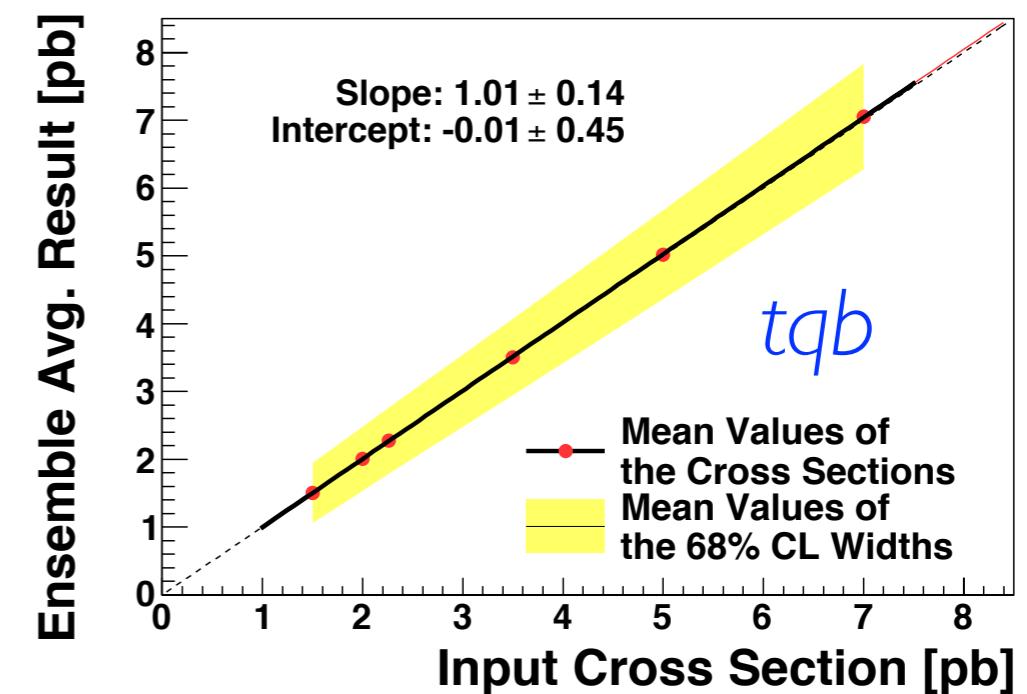
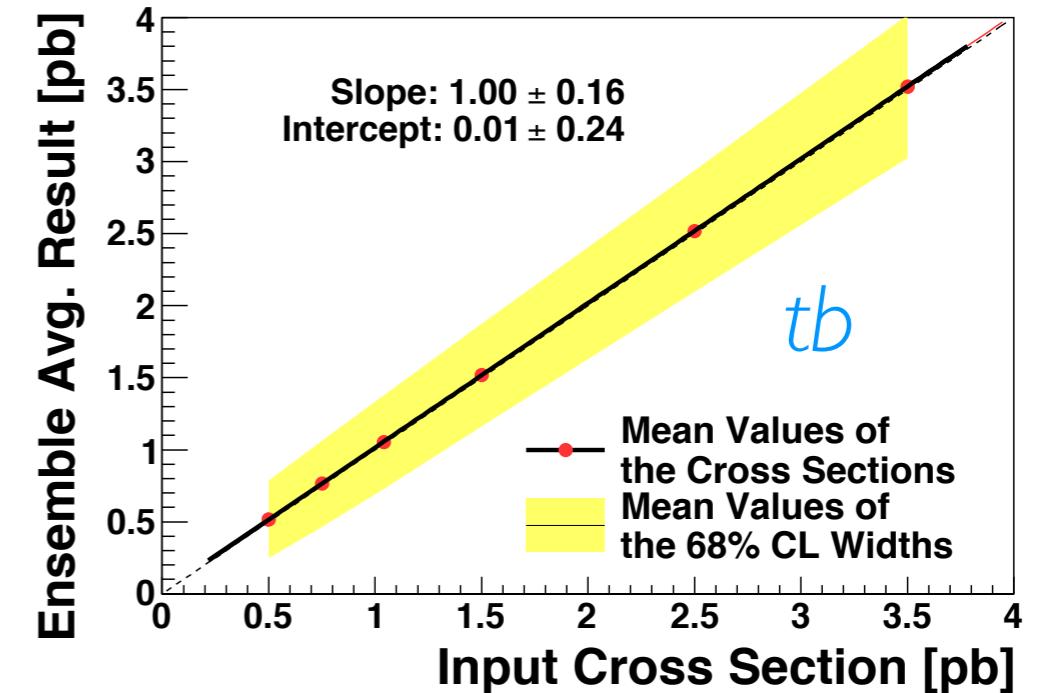
$$p(\sigma|D) = \frac{L(D|\sigma)\pi(\sigma)}{\int L(D|\sigma')\pi(\sigma')d\sigma'}$$

- Poisson distribution

$$L(D|d) = \frac{e^{-d}d^D}{\Gamma(D+1)}$$

Ensemble Test

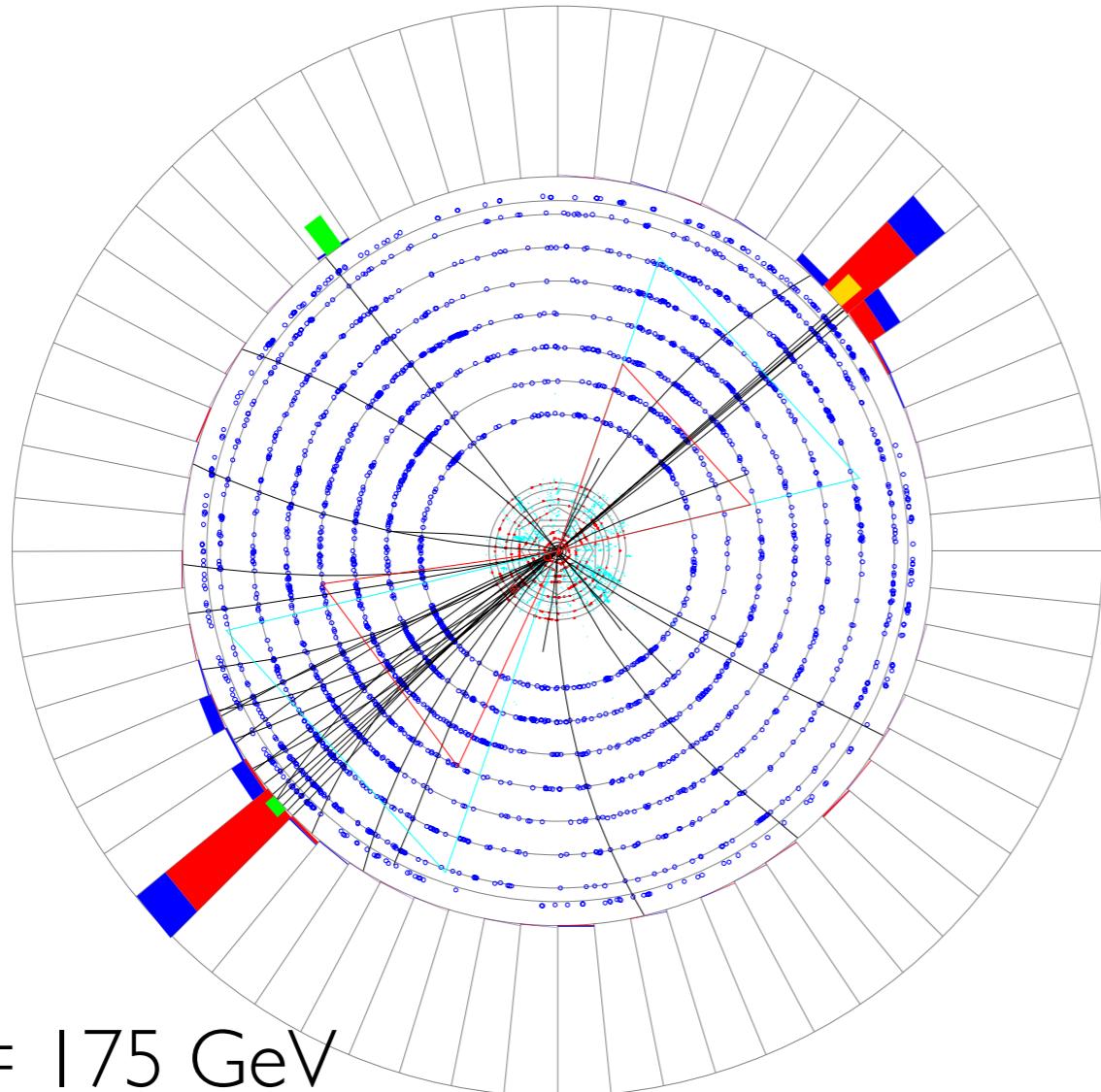
- Generate ensembles of pseudo-data samples
 - Each ensemble has a different input signal σ
 - All systematics included
- Extract the signal cross section from each pseudo-data sample
- No calibration needed



Another tb Candidate

Run 264600 Evt 37760117 Wed Sep 8 07:49:49 2010

ET scale: 143 GeV



$m_t = 175$ GeV

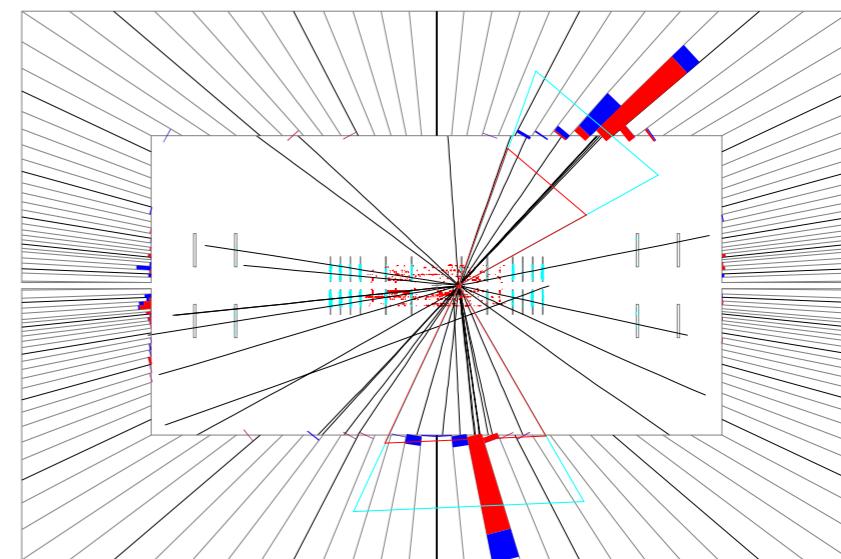
Jet1 b-tag: 0.32

Jet2 b-tag: 0.39

Run 264600
Event 37760117
Wed. Sep. 8 07:49:49 2010

Run 264600 Evt 37760117 Wed Sep 8 07:49:49 2010

E scale: 141 GeV



CDF Result 7.5 fb^{-1}

